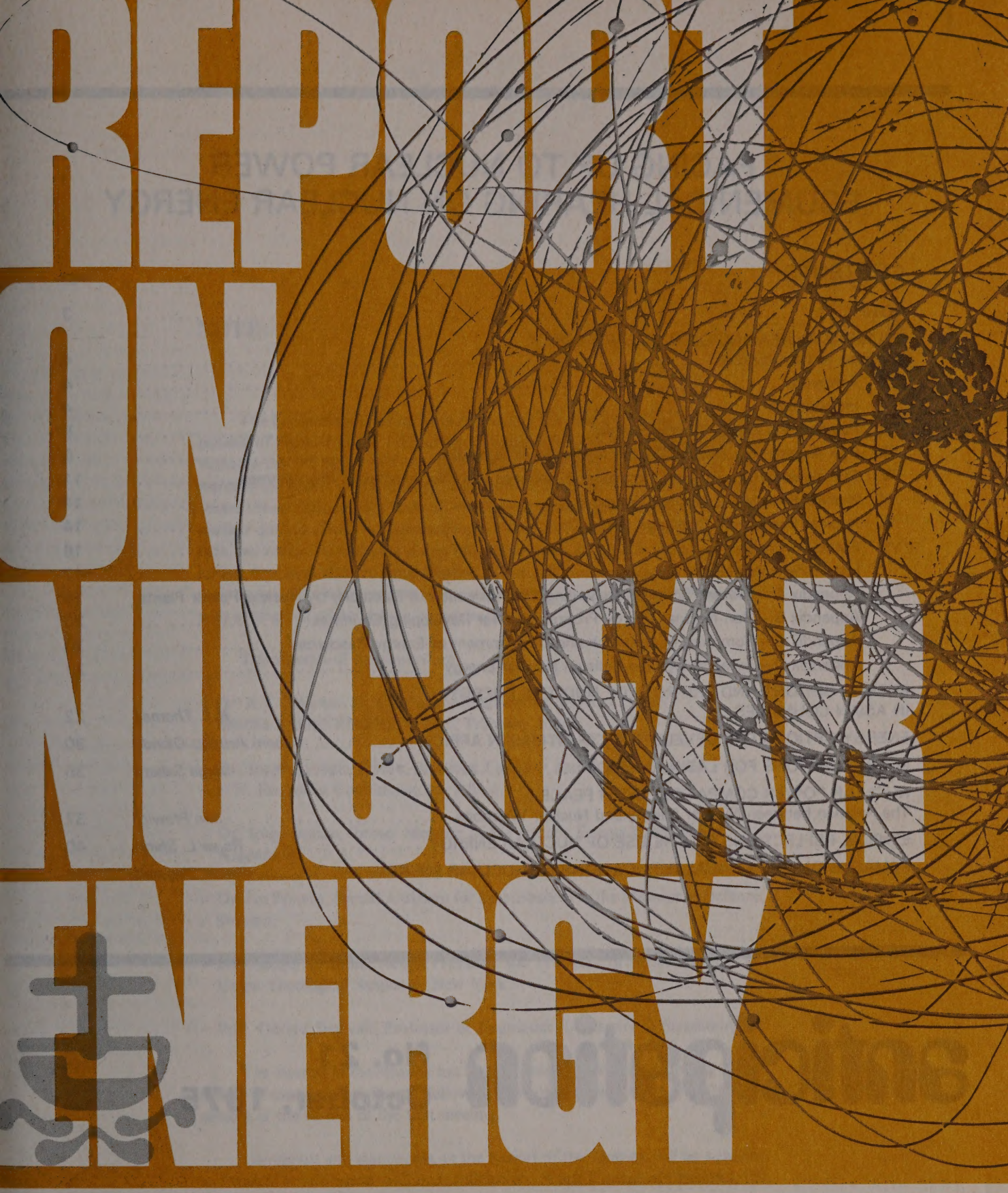
REPORT ON NUCLEAR ENERGY



anticipation

No. 21

October, 1975

FACING UP TO NUCLEAR POWER
ECUMENICAL HEARING ON NUCLEAR ENERGY

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anticipation **No. 21**
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CHRISTIAN SOCIAL THOUGHT IN FUTURE PERSPECTIVE

These papers are circulated for the information of participants in the ecumenical enquiry on "The Future of Man and Society in a World of Science-Based Technology". Comments are welcome. Church and Society, World Council of Churches, 150 Route de Ferney, 1211 Geneva 20, Switzerland

NOTE:

The Ecumenical Hearing on the Risks and Potentialities of the Further Expansion of Nuclear Power Programmes, announced in the preceding issue of *Anticipation* (no. 20, May 1975), was held in Sigtuna, Sweden, June 24-29. This issue includes the report of the Hearing, and a few of the papers and statements presented. Since the previous issue of *Anticipation* contained mainly papers on the nuclear question from the perspective of North American and European scientists, we include here papers giving the perspective of Third World energy specialists. Included also are a presentation on the relationship between nuclear energy and nuclear weapons, and two statements on the ethical and theological issues arising out of the debate on nuclear energy.

The authors of the papers are:

- Dr. K.T. Thomas, Director of the Engineering Services Group, Bhabha Atomic Research Centre, Trombay, India;

- Dr. Shem Arungu-Olende, Electrical Engineer and Energy Specialist, U.N. Economic Commission for Africa;

- Dr. Jorge Sabato, former Member of the Atomic Energy Commission, Argentina;

- Dr. Jan Prawitz, Special Assistant for Disarmament to the Minister of Defence, Sweden;

- Prof. Roger L. Shinn, Acting President and Professor of Social Ethics, Union Theological Seminary, New York;

- Prof. Gérard Siegwalt, Professor of Dogmatics, University of Strasbourg.

The interest in the Hearing has been so great that a second meeting on the theme of energy is envisaged, following the consideration by the W.C.C. Assembly of the results of the first meeting.

Comments and statements on the Report of the Hearing will be welcome and should be addressed to Church and Society, World Council of Churches, 150 route de Ferney, CH-1211 Geneva.

ECUMENICAL HEARING ON NUCLEAR ENERGY: A Report to the Churches

SIGTUNA, SWEDEN - JUNE 24-29, 1975

FOREWORD

In June 1974 at the World Council of Churches' Conference on *Science and Technology for Human Development* (Bucharest, Romania), the issue of the "nuclear energy option" was posed to the churches as follows:

> *"It remains an open question whether the widespread proliferation of nuclear power plants is a desirable choice for society to make. Yet throughout the Western world, there are already clear signs of a growing dependence on this form of energy production. Since national energy policies are prepared in isolation, it is doubtful that the collective international impact of these rapidly expanding construction programmes has been systematically assessed... A realistic appraisal of the implications of the nuclear process would seem to indicate unprecedented demands on capital, mineral resources and industrial capabilities, increasingly centralized systems of production, and a potentially large-scale environmental impact. The nuclear option entails a risk whose magnitude is a matter of debate. Widely divergent views of this risk are held in the scientific community."*

The Bucharest Conference was not able to resolve the divergent views in its own meeting and recommended that the W.C.C. "initiate a study of the major moral, economic, social and scientific implications of the extension of atomic energy plants in the world". In response the Central Committee of the World Council, meeting in Berlin (West), August 11-18, 1974, requested the Sub-Unit on Church and Society to make a preliminary assessment of "the risks and potentialities of the expansion of nuclear power". After consultation with many persons active in the nuclear debate it was decided to convene a Hearing on Nuclear Energy bringing together nuclear scientists, scientists from related disciplines, technologists and politicians, as well as theologians and church leaders. The Hearing was held in Sigtuna, Sweden, June 24-29, 1975, at the invitation of the Swedish churches who helped to make the meeting possible. It seemed to be a worthy manner to help celebrate the 50th anniversary of the 1925 Stockholm Ecumenical Christian Conference on Life and Work.

The 37 participants in the Hearing Group reflected the wide range of views on energy problems in general and on nuclear energy in particular. Their widely diverging positions were outlined in a preliminary way in a preparatory prospectus for the Hearing which provided the themes for the meeting. In addition to background papers circulated in advance, a number of the participants were invited to submit papers on specific aspects of the issue which were discussed in plenary. The Hearing also benefited from the advice of a number of resource persons, representing various international agencies.

The World Council of Churches is especially grateful to the Dutch physicist Prof. H.B.G. Casimir who most competently chaired the Hearing, and to Dr. John Francis, a nuclear scientist from Great Britain, who served as Rapporteur and gave invaluable aid to the staff of Church and Society in the preparatory process.

The reports of the three Working Groups into which our Hearing was divided were discussed in plenary and, afterwards, revised and integrated into a single report by the officers and staff. This full draft report was circulated to all participants who have given their suggestions on the wording of different passages. It will be clear from the report that it is not a highly elaborated consensus document but should rather be seen as an attempt to describe areas of agreement and to interpret the divergent views.

The report of the Hearing is submitted to the World Council of Churches and its member churches in the hope that it will contribute to clarifying ecumenical thought and action on this decisive contemporary issue.

Dr. Paul Abrecht
Director, Church and Society
World Council of Churches

I. INTRODUCTION

HUMANITY'S ENERGY NEEDS

For thousands of years people had to rely on food and wood for energy; to add to the energy of their own muscles, they tamed and bred animals, and the stronger made slaves of the weaker. Wood was burned for warmth and for such chemical purposes as preparing food, manufacturing ceramics and metals. Later, muscular power was supplemented by the power of wind and water utilized by sailing ships, and by wind and water mills. By the end of the 17th century in the Western world, transport by water, the draining and irrigation of land, and several industrial operations had come to depend on such devices. Wood as fuel was gradually being replaced by coal.

Since then the world has seen an enormous rise in the use of fossil fuel and of non-muscular energy. One simple example suffices to illustrate this development: a hard-working man has to be well fed and in good condition to deliver one kilowatt hour a day, an amount of energy that can be bought today from an electric power plant for a small sum of money.

Many countries of Asia, Africa and Latin America are still characterized by an energy system drawing on conventional power sources. It cannot be disputed that these countries must satisfy the basic requirements of irrigation, food supply, and primary energy production; this will inevitably result in an expansion of useful energy supplies during the coming decades without indulging anything other than essential human needs.

On the basis of an analysis of energy consumption over the last hundred years it has been suggested that the world's energy consumption has been increasing at an average annual rate of 2% and that this growth rate will continue. It is clear that this rate of increase is far too low to redress the situation in the developing countries. Even a 6% increase would only lead to a fourfold increase in energy supply by the end of the century, a quite modest goal.

For the developed countries the situation is different. Several studies have predicted an annual growth rate of 6% for the rest of this century, but increasing attention is now being given to the possibilities of energy saving. A number of scenarios are possible. One, for example, is to cut energy growth by half which would still lead to a doubling of consumption in 25 years. Even this reduced rate of energy consumption imposes tremendous pressures on resources and environment. While many consider some expansion both unavoidable and desirable, a great deal can be accomplished by energy conservation and it is urgent that we investigate ways to save on use of energy.

However a growing number of people in the developed countries do not believe that this reduction is enough. They are convinced that a society living at a lower level of energy consumption than we have today would be better in many ways – more just, more aesthetic, more serene, more healthy and more stable. They advocate zero energy growth with a reduction in consumption as the ultimate aim. This would not imply a return to an archaic or pastoral economy for even if the energy consumption of developed countries were halved rather than doubled the per capita consumption would remain far above that in the developing countries today.

A reduction of energy consumption would involve change in the socio-economic pattern of industrial societies. It might be enforced by unexpected calamities, by authoritarian governments, or by a severe economic crisis. To achieve it in a more acceptable way would require a conscious effort strong enough to overcome the powerful forces of technological dynamism. Rising costs of energy and a growing awareness of environmental problems could help, yet it would be a slow process. It may be illusory to believe that a reduction in energy consumption in the developed countries will be reached in time to make possible the urgently needed increase in the developing countries. This emphasizes that the need to begin the transition is a matter of urgency.

If the lot of developing countries is to be improved they will need increasing energy supplies. Some of these supplies will come from fossil fuels which will be more readily available if the developed countries reduce their use of energy. And the developing and developed countries will need to have other resources of energy for the time when fossil fuels may become unavailable.

All countries are therefore looking for alternative sources of energy to fossil fuels. The immediately available option is nuclear power, but the development of nuclear power presents problems which are analyzed in this report.

II. PLANNING THE ENERGY SUPPLY SYSTEM

A. ENERGY NEEDS

Energy is essential both to sustain the high standard of living already attained in some parts of the world and to guarantee at least the minimum basic requirements of food, shelter, health and welfare to which the majority of the world's population justly aspire. Additional energy must be harnessed to meet the needs of the world's underprivileged majority, even though it must be borne in mind that although energy is essential for development, it is not the only requirement; socio-economic as well as institutional changes will be necessary if the less affluent are to reap true benefits from additional energy.

It is believed by groups in several developed countries that a more modest and waste-free use of energy is feasible without compromising the standard of living already attained – some even believe that the real well-being would be improved. However as explained in the introduction, it is unlikely that growth will be arrested at short notice, and it seems illusory to expect a reduction that could compensate for the growing needs of developing countries.

The total supply of primary energy which is expected to be available varies between countries depending on the nature and extent of resources and also on the level of socio-economic development. Few countries are totally self-sufficient with regard to all their present and foreseeable primary energy needs and most countries depend on a mix of energy sources. At present, fossil fuels provide for the vast majority of energy needs, particularly in the developed countries, but there is serious doubt whether these sources alone will adequately meet the additional requirements, discussed above, beyond the medium-term future (say the next 50 years).[1] Furthermore, because of certain economic and political factors, some countries are reconsidering their traditional energy supply patterns. Consequently, both the projected demand is being questioned and other sources of primary energy are being sought.

The forms in which energy is required for utilization depend to a considerable extent on the type of society concerned. The modern industrial society has developed in such a way as to be heavily dependent on electrical energy and, in the transportation sector, on liquid fuels.

B. MEETING FUTURE ENERGY NEEDS

Until the last 15 years, the major sources of energy during this century were wood, coal, oil, natural gas and water power. Most countries have already developed most of their hydroelectric resources, although some, such as those of Southeast Asia, Africa and some parts of South America and Canada, still have substantial undeveloped resources. Before World War II, coal was the principal energy source, but since then oil and natural gas have largely replaced it. But both oil and natural gas, being depletable resources, are becoming scarce and the remaining reserves of both are becoming correspondingly more valuable and more costly. Geologists generally agree that the as yet undiscovered reserves of each probably at best do not exceed those already known or consumed. As a result, world consumption of both will probably peak by 1990 at 20% above the present level, and thereafter slowly decline to fall below half the present consumption by 2020. By then, the remaining reserves will have become so valuable that they will be too expensive to use for general energy production. Coal reserves will have to be used as a source of synthetic liquid and gaseous fuels for transport. Therefore less will be available to generate electricity. Waste heat from electrical power generation and solar energy will have to replace oil and gas for heating and cooling buildings. Rising costs will force increasingly stringent

[1] Stock-taking of the recoverable reserves of coal, oil and natural gas will continue to depend for a number of years on the new levels of exploration activity in many countries, on economic factors (e.g. production costs) and on advances in technology.

measures for conservation, elimination of energy waste and greater efficiency of its use.

Reduction of energy consumption in the developed countries would make the existing reserves last longer, but even if it could be realized it would not obviate the need for new energy sources.

Such energy sources will now be discussed under three headings.

1. Nuclear Fission

Nuclear energy has been developed and used commercially to meet an ever higher proportion of the electrical energy needs. (The present production of electricity by nuclear power is given in Appendix A.)

The advocates of this option are convinced that by the next century the required quantities of electrical energy at a price we can afford will have to come mainly from nuclear reactors. The availability of nuclear power based on current technology is dependent on world reserves of U^{235};[2] even optimistic estimates of the reserves of high quality uranium ore lead to the fear that at the present rate of deployment of nuclear plants, such reserves will be exhausted soon after the turn of the century. Unless other sources of electric power are developed we should then be forced to depend on mining of lower grade uranium ores possibly at great environmental cost and an energy input for the same electrical output much greater than the 5-7% presently required.

There are however alternative possibilities in the field of fission, viz. fast breeder reactors and thermal breeder reactors.

Fast Breeder Reactors. The liquid metal fast breeder reactor (LMFBR) is at the centre of an effort by the major industrial powers to increase the utilization of nuclear energy. The fuel for this type of reactor is usually a mixture of uranium and plutonium oxydes[3]; the heat is removed from the core by a circulating mass of liquid sodium metal and the primary circuit is not pressurized. In the breeding cycle the quantity of U^{238} that is converted into Pu^{239} is larger than the quantity of fuel (either U^{235} or Pu^{239}) that is burnt up by fission. If this development proves successful, practically all our uranium reserves can be used to generate energy – and these are 140 times as abundant as those of uranium 235, so that lower grade ores would not be needed so extensively. Prototype fast reactors have been operated successfully in the U.S.A., U.K., France and the U.S.S.R., although the breeding fuel cycle to recover the plutonium has not yet been fully developed or applied as extensively as would be necessary for the future programme. Fast breeder reactors offer the potential for electric power for the world's needs for centuries. The costs or risks of obtaining such energy from them are chiefly related to maintaining the safe disposal of the very long-lived high-level radioactive wastes which they produce (which are, however, the same as those from present reactors, the concentrations however being different). Furthermore, and equally important, society must guard against any diversion from the large quantities of plutonium in the fuel cycle to destructive purposes. The development and safe operation of such a nuclear power economy requires very considerable human technical and managerial skills. However the costs and risks, as described for fission are not significantly different for fast breeder reactors, but are most directly linked with the size of the nuclear power programme, particularly in relation to wastes and to plutonium transport and storage.

Thermal Breeder Reactors. These reactors burn uranium 233 and at the same time breed more of it from thorium 232 than they consume. The process has been proven experimentally in the U.S.A. and advanced engineering development may be as close or closer than that related to the fast breeder since the technology is similar to that of existing power reactors. Thorium is three times as abundant as uranium and a successful system of this type would greatly extend nuclear energy availability, although the rate at which new fuel is bred would be less than in the fast breeder. The waste disposal problem would certainly not be more difficult with thermal breeders, in some respects perhaps even less severe. Otherwise the costs and risks are comparable with those in the fast breeder economy.

2. Nuclear Fusion

For those who are not familiar with the advocacy of fusion energy, i.e. the combination at stellar temperatures of light nuclei to make heavier nuclei, there are several points worth making:

- The basic fuel, deuterium, is virtually inexhaustible and is obtainable at relatively low cost. (However lithium, the second fuel, has to be mined and is not inexhaustible.)
- The by-product of the fusion reaction is helium, which is non-toxic, non-radioactive and hence causes no problem of radioactive waste management.
- There is no possibility of a runaway nuclear reaction.
- By comparison with fission reactors, there would be significantly lower quantities of radioactivity associated with the system.
- There is no possibility of diversion of strategic weapons material.

However, it will be at least five years and probably longer before the possibility of establishing a net energy producing fusion reaction has been demonstrated. Even if this is achieved, the engineering problems of developing a commercial power reactor using fusion still appear immense, and may well take another twenty years to overcome. It is, therefore, premature to base any concrete plans for meeting human energy needs on the use of fusion power until well into the next century (if ever). If, however, success were realized it would make a major contribution to meeting man's long-term energy needs. (It does not follow that the problem of managing the potential scale of energy production on a global basis is in any way reduced. The disruptive effects of major climatic shifts would undoubtedly place a serious restriction on the release of ever greater quantities of heat to the biosphere. The widespread availability and use of any new form of energy production will ultimately be limited by this consideration.) Although there is no major waste disposal problem properly speaking, large quantities of hazardous tritium would be generated to be consumed in the process; further the stored radioactivity of the reactor would be comparable to that of a fission reactor.

3. Non-Nuclear Possibilities

Solar-Electric Energy. Solar energy for heating and cooling buildings and heating water is practical and undoubtedly will come into increasing use at appropriate latitudes. It is also possible

[2] One isotope of uranium (U^{235}) is a nuclear fuel because it can undergo fission on impact with slow neutrons; each fission event yields an average of 2.5 additional neutrons making a self-sustaining chain reaction possible. Less than one percent of natural uranium is U^{235}; the remainder is nearly all U^{238} which is not readily fissionable.

[3] On absorption of a neutron the uranium isotope U^{238} undergoes changes leading to the formation of an isotope of the man-made element plutonium, i.e. Pu^{239}, which is fissionable under conditions similar to that of U^{235}.

to generate electric power with solar energy by several methods, and a research and development programme to this end has now been launched in the United States. One way would be to use photovoltaic solar cells (semi-conducting devices that convert sunlight directly into electric power); this is done in the space programme, but the high cost of the devices used there is prohibitive. If a method could be found to produce a cell of this type cheaply in great quantity, a practical solar electric system could be developed. In places like the Sahara or Arizona deserts, where there is plentiful sunshine all year around, a 1000 MWe peak electric power plant would require 8 km^2 of such solar cells with 12% conversion efficiency and its daily average annual power would be 250 MWe. To provide larger electrical capacity would require more land area. This land area requirement coupled with the problem of energy storage will restrict the worldwide usefulness of solar energy for electric power generation, regardless of the success of the research and development now underway.

There are other ways of harnessing solar energy. Differences between surface and sub-surface temperatures in the oceans may represent a promising energy source. Wind energy is also a form of solar energy. Further it should not be forgotten that all agriculture and forestry transforms solar energy into chemical energy; better crops might be developed. (See Appendix B for non-nuclear energy programmes in developing countries).

Geothermal Energy. The deep rocks of the earth's crust are hot and constitute an immense energy universally available. A technique for tapping this energy resource for electric power generation has been suggested. A hole would be drilled to some 5–10 km and a large cavity of broken rocks formed by hydrofracture or a nuclear explosion at the bottom. Water would then be admitted to the cavity and hot high pressure steam withdrawn to a steam turbine generator on the surface through an auxiliary drill hole. To many it seems likely that the cost of creating such a system divided by the amount of electricity generated from the steam produced will result in a very high cost per kilowatt hour; but this is disputed by the advocates.

C. COMPARING THE DIFFERENT POSSIBILITIES

Unfortunately it is not possible at the present state of knowledge to make a strict comparison between the availability of nuclear energy systems and the potential development of non-nuclear sources of energy production. Such comparison must await the results of the major research and development programmes that have been initiated in different countries. But on the basis of past experience, and the very long time lags encountered in the introduction of major energy sources, the implementation of any technological breakthroughs cannot be anticipated before 1985 at the very earliest even on the most optimistic assumptions.

Nuclear fission is at this moment the only technically and industrially developed possibility to add to or to replace fossil fuel for large-scale production of electricity at a reasonable cost price. The decision to introduce ever larger nuclear plants all over the world is a fateful one. But the advocates of nuclear energy point out that the alternative might be as fateful and lead to severe social and economic disruptions and upheaval.

Opponents of nuclear energy are optimistic concerning the non-nuclear energy sources, and many of them would even be willing to face such upheavals. They point out that the industrial-technical civilization we have built, with its insistent demands for exponential growth, is a trap into which we have all been quite unwittingly led. Because of the finitude of the earth's resources, this growth must some day end. The whole of humanity must somehow find the wisdom to imagine a different life-style and mode of existence on our planet earth, and set about working toward it in a way which will encourage a significant change in the dynamics of our economies as these are presently constituted.

As a matter of fact, there is within several countries growing public questioning of the decision of authorities in favour of the nuclear option. This has already led in some to a slowing down in the rate of increase in installation of nuclear capacity and a decision to reappraise the advantages and risks in the light of further experience, e.g. in the Netherlands, Sweden and the United Kingdom. Furthermore, certain technical, political and social factors, to be discussed below, are leading concerned groups in some countries to question the wisdom of using nuclear energy at all. They believe that society could be organized in such a way as to guarantee an acceptable quality of life for all by an effective use of energy resources other than nuclear energy. It is argued that the most appropriate technology should be employed in the most efficient way to meet the specific needs of people under their particular circumstances: local resources should be used wherever possible, thus reducing dependence. It is further held that people should strive to organize their society and the technology they use in the way which is most harmonious with nature and thus maintain a proper ecological balance.

D. ISSUES FOR FURTHER CONSIDERATION

The Hearing Group was not of one mind concerning the desirability of the use or non-use of nuclear energy, but wishes to call attention to a number of important issues. The consequences of either including or rejecting the nuclear option in providing for the energy needs of a particular society should be considered from all angles. The Hearing Group has concentrated essentially on the issues related to the use of nuclear energy, but those wishing to pursue the non-nuclear option should likewise take full account of its consequences.

The following issues are raised in relation to the use of nuclear energy:

1. Most of humanity can foresee the dangers of misusing nuclear technology. This relates in particular to the nuclear weapons field. Many scientists and intellectuals, aware of these dangers, have not been able to prevent such misuse in countries which have developed weapons; when they are themselves actively engaged in research and development in the nuclear energy field they may be faced with hard ethical dilemmas. But even if many scientists were to disengage from active research in the field of commercial nuclear power development, this would be unlikely to halt the widespread implementation of planned expansion in many countries.

2. The introduction of nuclear energy on a large scale will help to reduce the gap between industrialized and developing countries only if there are also changes in the social and political structures. Otherwise the use of nuclear energy could even widen the already existing gap and magnify the power imbalance between developed and developing countries, as well as between rich and poor within a country. The use of nuclear energy should be geared to the search for a new international economic order which will further international justice and peace.

3. A group of countries and transnational companies have been pursuing a policy of increasing the price of liquid fuels. This is of medium-term benefit to the oil producing countries and the companies, and has created favourable conditions for them to em-

bark on research and development of alternative sources of energy, particularly nuclear energy. Thus, the world is in a transition period toward the post-petroleum era and this has introduced a number of new elements into the international situation. Oil producing countries are benefiting, gathering considerable revenues; countries already disposing of advanced technology and capital are investing in the development of new sources of energy. But for a considerable number of developing countries which have neither oil reserves, nor advanced technology, nor capital, this increase in the price of fuel presents only disadvantages. They are obliged to allocate huge amounts of money for their energy supply programme, which they could otherwise well use in other sectors of their development. This further widens the gap between the rich and the majority of the developing countries and tends to preclude the latter from establishing and implementing energy options best suited to their own conditions. They become increasingly influenced by the energy options of developed countries, even more dependent on international or bilateral aid, and subject to the influence of the multinational companies.

The Hearing Group was aware of several other important problems, but it was not able to discuss them fully. They are mentioned here as a stimulus to others who will undoubtedly advance the debate on nuclear energy on some future occasion.

1. Modern large-scale technology involves the risk of causing a rift between technology and the wholeness of humanity and nature. Therefore the social and physical sciences, as well as the life sciences, should make a common effort to study the consequences of nuclear energy.

2. Decisions concerning the development of nuclear technology should be made primarily at a national level without the interference of other governments and especially without the interference of transnational companies or any other large economic unit. The fact that technical information, materials and apparatus of an advanced nature can often be obtained only from such firms or units may easily lead to an undesirable form of indirect interference. In this context, international agreements, in particular on nuclear safeguards and operational safety measures, should not be considered as interference. The safe use of nuclear energy calls for effective and enforceable international agreements.

3. Notwithstanding the national autonomy emphasized in (2), it is essential that nuclear technology be shared. The idea that one group of men or nations is capable of deciding which people or nations are entitled to nuclear knowledge is unacceptable. At the same time, public consultation and debate should take place in and between countries prior to any country embarking on or expanding its nuclear power programme; it should not be the exclusive right of governments or of the scientific community to decide in these matters. We must also take into consideration that no nation has by itself developed nuclear energy. Even more important is that the development of nuclear energy by one nation may have detrimental consequences for others. This has been clearly shown by experience.

Finally, the Hearing Group calls attention to the need for further examination of the following consequences of either accepting or rejecting the nuclear option:

1. The socio-economic changes required by nuclear and other energy systems. For example, the use of nuclear energy in an acceptable manner for the benefit of society as a whole will require fundamental changes in the present socio-economic system and certain safeguards against hazards and sabotage, etc. If nuclear energy is not accepted, institutional arrangements will have to be made to ensure maximum benefit from other energy sources. In all circumstances there will be need for new emphasis on the elimination of unnecessary waste of energy.

2. Planning of further research and investment to develop nuclear and alternative energy sources on a wide scale. Although considerable research and development has already been done in the field of nuclear energy, its exponents consider that much more will be required to attain a level of supply which is virtually inexhaustible. For a non-nuclear society, considerable further research and development will be required to exploit alternative resources. (See Appendix C for a description of future prospects for research and development of energy resources.)

3. Careful investigation is needed into the effects on people and their environment of nuclear energy production using the full range of scientific and engineering skills. Most people are aware of the essential need to contain harmful radiation and toxic substances associated with the use of nuclear energy. However it is not only systems of producing energy which require great care, but to a greater or lesser extent anything that man does – agriculture, travel, industry, the burning of coal and oil, etc. disperse harmful and toxic substances. Every system of energy production inevitably has an impact on the environment, and before any new sources are exploited, full account should be taken of their long-term environmental consequences.

III. RISK ASSESSMENT AND THE CRITERIA FOR PUBLIC ACCEPTABILITY

A. Risk Acceptance in a Technological World

The safety of a nuclear energy supply system will depend on the excellence of its design, operation and maintenance, and on an overriding desire to achieve the safety of people working in it and of the public throughout the life of the system. Under these conditions, the chance of a serious accident is likely to be small, perhaps smaller than the risk to the public from some other industrial activities. Such risk as remains will be reduced progressively through experience in design and operation supported by relevant research and development programmes.

During the period of industrial growth many accidents have occurred – in transport, mining, factories, etc. The lessons learned through these accidents led to the slow elimination of many of their causes until a low and tolerable frequency was reached.

In the modern development of very large, complex and potentially dangerous plants, such as those producing petro-chemicals, pharmaceutical products, large aircraft, and nuclear energy, we cannot wait for accidents to happen in order to improve designs; consequently techniques for the recognition of potential accident situations have been improved on the basis of relevant experience of failures in machines and in man-machine interactions. There is good evidence that through these methods accident possibilities may be circumvented by design or by care in inspection and operation.

There is no infallible way of foreseeing all possible types of failure. Present techniques are good, but they are not yet widely applied and the engineering training in most countries is notably weak in providing the necessary technical insight and discipline to

reduce the risk of accidents. At the same time there has been no international effort directed towards the full scale simulation of accident conditions on a major nuclear power plant. While engineering confidence in the design and assembly of reactor safety systems may be high, these systems remain largely unproven under the predicted failure modes for different types of reactors.

The "maximum credible accident" study has been useful in the first stages of nuclear plant development. There has been a fundamental difficulty in defining the Maximum Credible Accident – it cannot be based on a logical premise as there is no framework of experience to establish what is the maximum that is credible. The current trend in most nuclear plant development is toward a measured assessment of all failure modes, or those accident chains which are considered important – the extent of the analysis depending on the consequences foreseen.

During such an assessment – which will continue during the operation of the plant – an agreement is reached between the responsible bodies as to the design basis to be used to reduce the likelihood of the accidents occurring.

There is a growing awareness of the importance of common-mode failure[4]. Good design and independent review of design and installations will gradually reduce but not eliminate the chance of unforeseen failures of this type.

The importance of safety and reliability of shut-down systems (i.e. the systems designed to close down the reactors under emergency or fault conditions) – or other systems such as emergency cooling and emergency power – is widely recognized. There have been notable improvements in design in all reactor systems and a move toward increased redundancy and diversity, towards the use wherever possible of different mechanical systems and different measuring devices using different components to reduce the chance of error. All systems are subject to tests of part or all of the systems at predetermined intervals under conditions under which they may have to operate.

Certain criteria have been established to provide a rough and ready guide to utilities in their early search for nuclear sites. Many factors are involved – foundations, water, power distribution, the proximity to people and to other industries, seismic faults, etc.

The siting criteria for nuclear power plants have been progressively relaxed over a period of years to achieve the full economies associated with the minimizing of transmission and distribution costs for the electricity produced. New reactor sites are now allocated in areas of low to medium population density although there has been a slow approach to major cities. This has varied between countries as there are significant differences in mean density and in local variation in density. Within each country siting could not always be based on an actuarial risk, but was determined rather by balancing the desire to be remote from major cities against the difficulties of using remote sites for industrial purposes, the need to shorten supply lines, to provide labour, etc.

Much progress has been made in assessing the risk to people or the environment from nuclear reactors, and the results of these assessments can and should be made available to governments and people who may be affected. Whether the predicted low risk of harm is realistic or not depends on the care and continued discipline applied to ensure safe operation.

Chemical reprocessing of spent nuclear fuel is a difficult operation, but many of its short- and long-term effects – such as those of discharging tritium or krypton into the atmosphere – can be reasonably assessed. It is the declared intent of reprocessors to control these by absorption and storage. Small spillages will cause moderate to severe local problems as in other chemical processes, and great care is required to ensure that these effects are not spread more widely as through rivers, underground water, etc. The main problem however is the high radioactivity content of such plants and the medium and high-level wastes produced.

The long-term disposal of wastes – particularly those which are highly active and have a long lifetime – remains a problem. How it can be ensured that they will not be a perpetual source of harm for 1000 years or more to come is yet to be discovered. The process for rendering wastes insoluble through glassification[5] is still in the early stages of development, although there is good reason to believe that this can be carried out on the appropriate scale. However major application on a large scale has not yet been attempted! Satisfactory results have been obtained from experimental disposals monitored since 1959.

This problem of waste disposal is a particularly critical area for international collaboration and agreement, even though the temporary disposition of waste is at present being dealt with inside national frontiers. Problems of earth movement, dissolution and migration of nuclear wastes are essentially global in character.

It is not yet possible to say whether good solutions will be permanently available; neither can one say that this will not be the case.

Standards for transporting irradiated fuel, plutonium and other radioactive isotopes, for containers and testing procedures have been evolved by the International Atomic Energy Agency with other international and national bodies over the past 20 years. For the highest risk materials, containers are subject to severe tests equivalent to high speed collision followed by intense fire. Although accidents may and no doubt will occur, their effects in a well ordered society are most unlikely to hurt people and will cause only local disturbance. There is greater concern about the possibility of wilful diversion and misuse by criminal or terrorist organizations.

B. Public Acceptability

Public acceptability should be an important criterion relating to the utilization of nuclear energy in determining public policy. However, in most democratic societies an open discussion of the issues involved is only beginning, and public acceptability is therefore hard to assess for the following reasons:

Any meaningful decision depends on a weighing of available alternatives. For example, a society might in a general way favour a reduction in pollution, yet simultaneously refuse rationing or taxation designed to restrain consumption. Public acceptability is therefore almost meaningless except in relation to specific decisions.

There are many publics within a society and there will no doubt be serious conflicts of interests. There may be a widespread general feeling that the society would be better off with reduced usage of private automobiles. Yet corporations and trade unions manufacturing steel, rubber, glass, and finished automobiles might favour increased production of cars. Likewise there are many physical planning and locational factors that provoke public reactions, e.g. many people want increased energy, but do not want a hazardous or dirty power plant in their neighbourhood. In

[4] An otherwise "incredible" accident made up of a combination of very ordinary events; that is, outside the designer's normal frame of reference.

[5] The incorporation of radioactive waste material in molten silicates at high temperature resulting in the formation of a stable glass-like substance at normal temperatures.

this connection the right of minority groups is posed in a new way.

Through oversight the public might assume some risks that it would never deliberately choose to accept. For example, most societies would be against the number of casualities associated with the motor car. The same society might, however, by a series of decisions about speed, unintentionally accept a high casualty rate.

All social decisions have an element of ambiguity and this element is increased in a complex technological world. When competent technical opinion diverges, public acceptability often becomes exceedingly difficult.

These difficulties point to the importance of and need for socially responsible ways of making public decisions. They require an informed public. There is need also for governmental measures to distribute the costs and gains of innovations (or the rejection of innovations) more justly than is generally the case. But the difficulties of the problem cannot be an excuse for evading it.

Here we meet an intrinsic difficulty. The plurality of publics and the conflict of interests represent also a plurality of value systems and conflicting understandings of justice based on incompatible visions of the good. The churches could contribute substantially to discover the truth in the statements of the opposing interests in such conflict situations; they should also support the rights of people to essential information.

We feel it is important to stress the value of a procedure such as the one adopted in Sweden (Appendix D), where an effort was made by government to inform the public on the risks and benefits of nuclear energy. In this way it becomes possible to hope for a high degree of public participation in the discussion of even a technically complicated issue which may have very important consequences for society.

C. Problems Arising from the Diversion of Nuclear Materials

The Hearing Group is concerned over the possibility of the clandestine diversion of plutonium for the construction of a nuclear explosive. The danger is not confined to governments – non-governmental groups or even individuals may construct and explode, or threaten to explode, nuclear devices. Plutonium could be stolen; it could be ransomed; for various motivations a group may seek to obtain plutonium in order to use it as a nuclear threat.

This year, the world's nuclear power reactors will produce about 25,000 kg of plutonium; in 1980, they will probably produce about 80,000 kg. The exponential increase in the amount of plutonium produced may continue for the rest of the century.

International safeguards, as at present applied, can only **detect** the diversion of nuclear material, they cannot physically **prevent** it. Moreover, these safeguards are primarily designed to detect diversion for nuclear weapon production, with the hope that early detection will deter such diversion.

While the International Atomic Energy Agency can handle its present obligations satisfactorily it is less certain that it will be able to cope with the greatly increased use of nuclear energy predicted for the next decade.

Uder these circumstances the need for adequate physical protection of plutonium becomes critical. This task must, at present, be performed by the national control systems since most states today would resist this being taken over by an international agency on the grounds that it would conflict with national sovereignty.

The greatest need for protection is from the time the plutonium leaves the reprocessing plant until it is eventually burnt as reactor fuel. The protection must prevent both theft by persons employed in the nuclear facilities and theft by outsiders. Perhaps the most critical time would be when the plutonium is being transported between facilities; and, in particular, when it is being transferred from one method of transport to another. Once again, the problem is greatly complicated by the considerable distances that may exist between the establishments housing the plutonium. A great many problems will arise if an absolutely foolproof system to prevent hijacking is required.

By the maximum use of the appropriate available technologies plutonium could probably be made relatively secure, at least in the short term. But two problems immediately arise. As the amount of plutonium to be protected becomes very large the cost of adequate protection may become prohibitive. The measures which will be necessary may become cumbersome and too complicated for easy implementation. They may also be unacceptable in a democratic state.

Such fears have been expressed in relation to an expanded nuclear programme by Hannes Alfvén who holds that: "The high complexity of the nuclear systems in combination with the risk for catastrophes give rise to unprecedented requirements for a standard of excellence in design and operation and in reliability of components and personnel. It seems doubtful whether these requirements can really be satisfied when a large number of reactors come into operation in many countries having widely varying experience in high technology."

For these reasons (and because many countries may not adopt fully adequate national control systems), an alternative solution to the problem is suggested by some. One possibility would be to forego the future use of nuclear power altogether. Another solution would be to put all processing plants, plutonium stores and reactor-fuel fabrication plants under regional or world-wide international supervision.

There may be other possibilities, but summarizing the alternatives we find that one group believes that the process and controls required to safeguard nuclear installations will become so complex and difficult to administer and the chance of failure by oversight or mischief become so great that nuclear power should not continue in the present state of the world.

There is however the other group which believes that while the difficulties are great, the need for energy is also so great that a degree of national and international discipline will evolve to ensure that risks are kept within bounds and to ensure the rapid promotion of all the techniques required to understand and adequately control the problems now foreseen.

D. Concluding Observations on Public Responsibilities in Risk Assessment

We note that international boundaries (and to a much lesser extent administrative boundaries within a country) can lead to inadequate weighing of interests in the siting of nuclear installations of all kinds. Those on the "wrong" side of the boundary are nearly always inadequately informed, inadequately heard, and have no influence or only inadequate influence on the decisions taken.

In the case of nuclear accidents, such boundaries may hinder rapid and effective protective action for the persons that could be affected, actions which may be required to control the accident or its effects (e.g. collective action between countries may be necessary in the event of a major accident occurring in close proximity to a frontier or boundary region).

We urge all authorities to fulfil their moral obligations to al

concerned by ensuring that the boundaries of their jurisdiction do not lead to less responsible decisions and effective actions than if these boundaries had not been present.

The benefits of nuclear power may well accrue to the local or national community, while many of the longer term risks (and disadvantages), i.e. through radioactive wastes, plutonium diversion, etc. can affect a far wider area. This introduces a bias which may lead a community to be more favourable to nuclear development than if their area of responsibility covered all people involved.

Some risks and responsibilities will fall on generations yet to come. This leads to the difficult problem of how to balance present benefits against future risks and burdens.

IV. RADIOLOGICAL HAZARDS AND OPERATIONAL EXPERIENCE WITH NUCLEAR POWER PROGRAMMES

A. Normal Operations – General

In our context, large-scale nuclear power programmes are taken to include all elements from ore mining and milling through fuel fabrication, reactor operation, waste removal reprocessing and storage. There are special problems related to the mining and milling area where historically different standards have pertained at various times.

We are concerned with both workers in the industry and the populace at large. The current maximum permissible radiation doses (MPD) as defined by the International Committee on Radiation Protection (ICRP) are 5 rems per year for occupational workers and 0.5 rems per year for individual members of the populace[6].

Experience with the various steps in such programmes, including the nuclear fuel industry, nuclear power reactors and waste handling, has shown that there is no difficulty in keeping the radiation doses for occupational workers within the ICRP recommended limit. In fact, the doses have generally been much less, and, if necessary, it will not be difficult to accept lower limits for both occupational workers and the public, even with a widespread availability of nuclear power. However, it is to be noted that the average radiation dose received by workers in power producing units and reprocessing plants has been rising rapidly in some cases during the past years. Some countries have adopted much lower levels as national standards, not because radiation risks from low doses have been found to be greater since the ICRP recommendations were published in 1965, but because of the recommendation of "as low doses as practicable". Thus in West Germany a collective dose rate of $<$ 1 millirem per man.year to the public is recommended as a guideline for the releases from the nuclear power industry. In Sweden the recommended limit is a collective dose of $<$ 1 man.rem per megawatt year nuclear electric power; this corresponds to 10 millirem per man.year for 100 GW electricity installed and 10 million people. It should be observed that these values are about 10 to 100 times lower than the average radiation dose received by the public either from medical X-ray examinations or from the natural radiation background.

At the same time, the surge of growth of the nuclear industry is the source of concern with respect to the radiation dose level for occupational workers since the number of exposed workers will rise sharply (possibly reaching several hundreds of thousands), and since the search for minimum cost of operation will tend to lead employers to consider that the MPD can be delivered to every worker. For these reasons, as well as the fact that more and more temporary workers are used, we express concern about the control of radiation dose. It appears highly desirable that an international or at least supra-national, regional nuclear passport be created for every worker, recording his/her radiation dose history. A similar system already exists, for example, in Switzerland.

Many steps of the nuclear fuel cycle involve releases of small amounts of gaseous or liquid radioactivity into the environment, as well as some direct radiation to the occupational workers. (The total doses received as a consequence of this have been discussed above.) Considering all sources of radiation from a nuclear reactor system, including reprocessing, it is worth noting that releasing ^{3}H and ^{85}Kr to the atmosphere may become the main source of radiation dose (from the nuclear power industry) to the population. Techniques exist at present for collecting ^{85}Kr. Such techniques must be applied in future reprocessing plants. The technique for collecting tritium is more complicated, and it must be expected that fairly large amounts will be released into the environment, most probably in the form of water. The difficulty of retaining it may become a limiting factor for the nuclear industry.

Because of the rising costs of safety procedures in uranium mining and fuel reprocessing plants it is to be expected – and this is already happening in the case of mining – that these industries will tend to be preferentially located in those countries with less effective controls. An international control of the safety procedures throughout the fuel cycle would therefore be desirable.

We are not aware of any significant determinable effects of radiation on either workers or populace through normal operations of power reactors (including subsequent processing and waste disposal). At the same time, the rapid growth in nuclear power programmes will almost certainly mean that an increasing number of people will be exposed to an increasing fraction of their MPD. Pressures will therefore increasingly exist to reduce radioactive releases to remain within permissible dose levels. However, there is still great uncertainty in the experimental findings relating to the risk of either somatic or genetic effects of low dose rates of multiple small fraction exposures. The policy so far has been to err on the right side. Still this problem calls for greater efforts in both the experimental area and in the gathering of relevant biostatistical data. It is prudent to assume from current knowledge that no threshold of radiation dose has been established below which there is no effect. At the same time no unsafe effects have been noticed when working with the currently established ICRP dose limits for the last three decades and adapted to local conditions. There must continue to be evaluation of any possible relationship between the lifetime or cumulative dose of groups of workers (and/or of the populace at large) and specific physiological effects. This must pertain both to radiation arising from nuclear operations, from natural sources and from medical applications. The prospect of the development of medical radio-protective measures can aid, for example, in meeting needs in specific urgent accident or rescue situations.

[6] The REM (Roentgen Equivalent Man) is the unit of radiological dose applicable to absorption of ionising radiation in living tissue, one Rem corresponding to the absorption of one Rad of X or Gamma radiation (1 Rad = 100 ERGS per gramme).

B. Fast Breeder Reactors

In the case of the liquid metal fast breeder reactor (LMFBR) system, there are a series of major unresolved issues relating to instrumentation and safety. While these are highly technical, they may be worth quoting:

1. The adequacy of instrumentation to detect fuel pin failures, coolant channel blockages, and local fuel melting, without any serious time delays;
2. the nature of molten fuel – coolant interactions and the possibility of local accidents propagating through the reactor core;
3. the adequacy of mathematical models and computer codes to place realistic bounds on the explosive potential of a fast reactor nuclear excursion, and the consequences which might then follow: i.e. the release of plutonium and all the high boiling point fission products.

It has been predicted by some experts that the risks from a severe nuclear accident on a light water reactor, may be of the order of 10^{-6} to 10^{-7}per reactor per year, and this level of probability is comparable with the risk from routine releases in the same plant. If this low frequency was maintained, the dispersion of radioactive material following accidents will then be less than routine releases calculated on a cumulative basis (e.g. severe accident releases may be 10^7curies I-131, 10^6 curies Cs-137). It is the release of this quantity of radioactivity in one place at one time that becomes the critical factor in the risk calculations. This relationship will hold true for other types of nuclear plants including the liquid metal fast breeder reactor, although it is not possible to show at this time that the accident probability will be acceptably low, i.e. below about 10^{-6} per reactor per year. (10^{-6} per year means one chance in 1,000,000 per year of operation on each reactor.)

Under normal operating conditions, the special hazards of a fast breeder reactor are mainly related to the much higher fuel coolant (in the case of sodium) and fuel with high plutonium content.

Events such as:

- Sodium-water reactions and the associated fire hazard;
- the introduction of moderating materials into the core with corresponding changes in reactivity;
- the blockage of narrow coolant passages, particularly in the vicinity of heat transfer surfaces within the fuel element bundles;

are different in kind from those in thermal reactors and necessitate very specific design considerations. In addition, under accident conditions there is the possibility of a re-arrangement of the core into a more reactive (eventually prompt critical) state. A subsequent vapour explosion which terminated the reaction was one of the special phenomena first associated with the sodium-cooled breeder reactor. More recent studies have shown that other non-explosive ways of terminating prompt criticality exist and they are being actively investigated at the present time. The situation can be summarized as follows:

The existence of a significant Doppler effect in large fast reactors is an extremely important feature[7]. In large fast reactors using ceramic fuel containing a high proportion of U^{238} it was found that the fuel lifetime could be extended and at the same time a mechanism was found to exist which could instantaneously reduce the effect of inadvertently adding large amounts of reactivity which could cause the reactor to become "prompt critical" or uncontrolled. In a typical large sodium-cooled fast breeder reactor, for example, it is possible to imagine a very improbable sequence of events in which some accidental re-arrangement of core geometry causes a sudden increase in reactivity while the reactor is running at full power. If we further imagine that none of the many automatic safety devices function so as to insert the safety rods, then the fuel temperature will begin to rise rapidly until the compensating effect of the Doppler process counteracts the added reactivity when the temperature rise is checked for a brief period at some level below the point when fuel damage would occur. In this way, the reactor's response to the initial disturbance is controlled and the difficulties of limiting the effects of the energy release are greatly mitigated. The major factor in this hypothetical accident which prevents the reactor from becoming uncontrolled is therefore the Doppler effect. Confirmation of the studies in progress should give added assurance that plutonium will not be dispersed outside the immediate environment of the reactor under fault conditions.

C. Waste Management

Radioactive wastes are produced by all operating plants in the nuclear power industry. The basic system adopted in waste management is the dilution and dispersal of the low activity wastes, and the concentration and containment of high activity wastes. The latter, which emanate from the fuel-reprocessing facilities, constitute about 99.9% of the total radioactive substances produced. They consist mainly of fission products, with some transuranics (actinides). The radioactivity content may be up to 10,000 curies[8] per litre. They are stored first in underground stainless-steel-lined concrete tanks with double containment, and cooling for the decay heat. However, tank storage for such wastes is an interim measure, and all countries faced with this problem have long-range programmes. These are: (1) Storage for a finite period, e.g. 5 to 10 years, in tanks to allow for decay cooling. (2) Solidification in a non-leachable stable material such as glass. (3) Storage of fixed wastes in an interim vault under controlled conditions, with cooling to dissipate heat and allowance for decay time. (4) Permanent disposal (if it is necessary to remove the wastes from storage) in a geological environment stable over geological times and with no water ingress possibility. Formations such as deep abandoned salt mines and basaltic and granitic formations have been investigated by different countries.

The problem of transuranic elements in high activity wastes has been of concern to many because of the long-term control requirement. One solution advocated by some is their separation from the bulk of the high activity waste, separate treatment in special reactors, and conversion to less hazardous isotopes. There is need for practical demonstration of such methods, which would likely increase the cost of waste management. Experience so far indicates that high level activity wastes can be managed safely without separation of the transuranic elements, though review will be needed if and when fast breeder reactors come into operation on a commercial scale; this is unlikely to take place before 1990. (For further reference to fast breeder reactors, see Section B).

[7] The Doppler effect is caused by the heating up of the atoms of uranium in the fuel thus causing them to move faster. Neutrons which are passing through the fuel tend to be captured by some of the U^{238} atoms at what is known as a "resonant energy". The increased velocity of the uranium atoms increases the number of these atoms which are at the resonant capture energy relative to the passing neutrons. These U^{238} atoms therefore stop some of the neutrons which otherwise would have continued their travel until they were captured in the fission process, and this tends to reduce reactivity and power. An increase in fuel temperature will therefore be countered by a decrease in the power level on the reactor; the Doppler coefficient is therefore a negative power coefficient.

[8] The curie is the activity of a quantity of a radioactive isotope in which the number of atomic disintegrations per second is 3.70×10^{10}.

The low and intermediate level wastes resulting from operation of large power reactors constitute less than 0.1% of the total radioactivity but account for a large volume. They are treated by conventional chemical engineering methods, and their treatment, containment and disposal operations can be carried out safely without any difficulty. These processes are developed in a high degree of efficiency and a decontamination factor of 100-1000 can be obtained depending on the initial activity and the treatment required to reduce the same to the stipulated levels. Particular care is always taken to remove specifically hazardous isotopes of elements such as strontium, cesium, radium, etc. Airborne wastes are passed through absolute filters which have efficiencies greater than 99.9% down to 0.3 micron particles (or 10^{-6} meters).

The record of radioactive waste management has been good so far and there is no reason to believe that it will not be maintained in the future. Current procedures explicitly involve exposures to workers and the public well below maximum permissible.

D. Use, Storage and Transport of Plutonium in a Nuclear Reactor Programme

In the course of the nuclear fuel cycle, there is a need to reduce as far as possible the number of steps involved with the handling of plutonium in order to improve and assist in its control. The proposal that all extracted plutonium should only leave any extraction plant in the form of complete fuel elements is one such approach. When plutonium is in a fuel element it is securely held and cannot escape unless the fuel is heated to a very high temperature (in excess of 1000 degrees Celsius). When plutonium has been extracted but is still in the extraction plant, it is considered to be in safe retrievable storage.

Safeguarding against the diversion of plutonium to atomic bomb manufacture requires very strict and careful accounting and ultimately some physical enforcement of security must be available. Such measures would involve continued national and international inspection and means for effective enforcement. These are certainly possible but require international cooperation and sacrifice of sovereignty.

It is likely to be forever impractical to take such a complete and accurate inventory of plutonium in extraction and processing plants that it would be possible to detect the abstraction of amounts sufficient to make several atomic bombs. Both direct measurements on separate process streams and less direct methods are therefore used, and will be further developed for detecting diversion to wastes or other purposes. Enforcement measures need further development. (See Section H below).

E. Transportation of Nuclear Materials

International regulations for the safe transport of nuclear materials drawn up by the International Atomic Energy Agency are available and satisfactory, and are revised periodically to take into account new developments. Improved techniques to implement these regulations will continue to be introduced. Risks of diversion during transportation differ widely in different locations and need to be met by enforced security measures, to appropriate security levels. Controls applicable to worldwide shipping are needed and call for strengthening of the Laws of the Sea.

F. Regional Reprocessing

The International Atomic Energy Agency is working actively on the question of regional fuel reprocessing facilities. First, a committee of experts from a number of member states will be preparing in the coming two years guides and standards for nuclear safety throughout the fuel cycle. A study of the soundness of the concept of regional nuclear fuel centres is included in the Agency programme. A special international conference on the whole nuclear fuel cycle is being planned by the Agency for 1977.

G. Training

The training of specialists for operating and safeguarding nuclear fuel production throughout its cycle will be an important and expanding need in the next several generations. International cooperation seems essential, and the International Atomic Energy Agency has begun a series of training courses, but will need increased financial support. A bottleneck could well develop in this area.

H. Enforcement

Even the best designed set of safety measures is useless unless they can be vigorously enforced. But such enforcement of security and safety measures presents a serious problem for which no satisfactory solutions have yet been found. International agreements with respect to such measures are needed urgently. It is to be hoped that the U.N. General Assembly, the Disarmament Conference and the International Atomic Energy Agency will give new attention to this problem. The churches might well make this one of their concerns.

I. Accidents

The question of the possibility of a large accident in a nuclear power station has been taken very seriously. Every large nuclear power reactor houses such enormous amounts of radioactive materials that under no circumstances should a sizeable fraction of these be allowed to get free. For this reason, considerable safety measures were introduced from the beginning of the atomic industry. Thus far any catastrophe has been avoided, though there have been incidents which might have become rather serious. These accidents demonstrate that no let up in vigilance must be allowed; rather a considerable increase will be required in view of the planned global mass deployment of large nuclear power plants. Growing familiarity with the constant danger, if it leads to carelessness or deviation from accepted safety procedures, will be a hazard in the years to come. The necessity of constant vigilance and the shortage of qualified personnel both impose a limit on the rate of growth of extensive nuclear power programmes.

J. Waste Heat

The waste heat burden for large nuclear power sites will be very considerable due to the volume of cooling water required and to the higher rejection of heat per kwh produced in the particular case of light water reactors. In both nuclear and fossil fuel plant used for electricity production, there will continue to be a limiting efficiency in the range of 36-40% so that the bulk of the heat produced is still likely to be rejected. Waste heat rejection to rivers, lakes and seas can cause severe problems in certain locations; dissipation through wet or dry cooling towers has potential related problems of localized meteorological changes. Constructive utilization of such waste heat including, for example, district heating and fish farming, is an immediate as well as a future requirement for more effective use of our energy resources. These waste heat problems will impose certain limits on siting of large nuclear power parks. Expected achievements and changes in nuclear power reactor designs and programmes, especially beyond the next decades, will assist in environmental adaptability to this stress.

V. NUCLEAR ENERGY AND NUCLEAR WEAPONS

The Hearing gave much attention to the question whether the extension of nuclear energy programmes will contribute to the further proliferation of nuclear weapons. Four critical issues were highlighted:

1. In most of the industrialized or technologically advanced countries, nuclear energy was developed on the basis of experience gained in the development of nuclear arms technology. In the present situation this "coupling" may tend to be reversed: the extension of the facilities for the production of nuclear energy to countries with developed nuclear science programmes may make it technically possible to construct nuclear weapons. The precise "tightness of the coupling", however, depends on the character of the nuclear programme and which atomic weapons are envisaged; it is a matter of vigorous debate! In the last analysis, this might not even be decisive, since a country, determined to obtain nuclear weapons, can do so by several routes. Nevertheless it is apparent that its efforts would be facilitated by the wide extension of nuclear energy technology.

2. It is difficult on political and moral grounds to deny countries without nuclear technology the right to obtain it because of a fear that they might use it for the development of nuclear weapons. The proposition that the appropriation of nuclear technology would forever be a limited right, to be doled out by the present nuclear countries according to rules determined by their interest is unacceptable. This would be an intolerable situation for many developing countries seeking to benefit from the peaceful application of nuclear energy and throw off technological domination by the already industrialized countries.

3. The major obstacle to nuclear disarmament is that the major industrial countries, already producing and possessing nuclear weapons, continue to regard them as indispensable for maintaining their power. Recent advances of military technology in the U.S.A. and the U.S.S.R. may produce new instabilities in the strategic arms race between these two nations. The only convincing step toward preventing the nuclear arms race would be general nuclear disarmament by the present nuclear powers. This step would, however, become much more difficult if many yet non-nuclear countries were to obtain nuclear arms technology in the future, even if they do so on a very limited scale.

4. The Non-Proliferation Treaty is not a sufficient instrument to prevent nuclear arms' proliferation since it is based on discrimination in favour of countries already possessing nuclear weapons. It is not surprising therefore that it is difficult to enforce and achieve its universal acceptance and that many nations, especially several with a potential nuclear weapons capability, have so far refused to subscribe to it. It has not therefore fully prevented the spread of nuclear weapons (though Article VII of the Treaty encourages the formation of geographically extensive nuclear free zones).

It is part of the tragedy of our times that we see no simple way out of the present dilemma of our world: faced with the potentiality of nuclear energy and the fear of nuclear warfare. We are entirely agreed that nuclear weapons and nuclear warfare are a disastrous evil, and that by making nuclear arms nations are playing recklessly with the future of humanity. It is not clear, however, that stopping nuclear energy programmes will greatly reduce this hazard if countries are determined to equip themselves for nuclear war.

The churches and all others committed to a vision of justice and peace have a responsibility to sensitize people to these fundamental issues. Because of the fatalism about nuclear armament which is a characteristic of our times it is important to –

1. press for changes of social, political and economic structures which would help reduce international tension and conflict, and promote justice;
2. continue the struggle to persuade our countries to accept international control policies leading to effective disarmaments;
3. increase efforts to alert peoples to the enormous dangers, for all humanity and for future generations, of a nuclear war.

VI. NUCLEAR ENERGY – A CHALLENGE TO THE CHURCHES

The decisions concerning nuclear energy depend on scientific, technical and economic judgements and choices; but also on religious and ethical assumptions. The churches are inevitably drawn into a discussion of the choices, not only by their own sense of responsibility but because scientists themselves are asking for public discussion and guidance on the issues involved. Every conversation during our meeting, no matter how technical the issue, soon became a discussion of human good, ethical decision and the meaning of human life.

We have found, to our surprise and pleasure, that, whatever our background and discipline, we have been able to speak and listen to each other with an openness of mind and spirit. We have not come to agreement on all points and in some instances our opinions still differ widely. But this meeting has for us all been a welcome experience in an area of discussion rife with misunderstanding, mistrust and polarization.

We call on all men of good will (and in particular all Christians), to commit themselves to this dialogue. All of us will in the coming years be expected to make critical decisions in this area and we shall need as much information and understanding of the issues involved as we can attain.

We call especially upon all churches to:

1. further understanding of the problems, both inside and outside the churches, making available to people at all levels of society, reliable and comprehensive information, and helping them to interpret and assimilate it;

2. provide occasions for dialogue where the tension between groups has grown so great as to bring conflict;

3. bring together those with special responsibility for policy in this field with other strata of persons, especially those they would not normally meet (e.g. problems arise where nuclear planners and engineers do not make an effort to meet with the population of the areas surrounding proposed nuclear power sites);

4. ask searching public questions on the goals of society and the means it uses, weighing long and short-term advantages and disadvantages, and in this light to provoke the community to examine critically its corporate and individual life styles;

5. point out that decisions taken in the field of energy ought to diminish and not increase global disparities in economic and political power.

SOCIAL AND ETHICAL ISSUES FOR REFLECTION AND ACTION IN THE CHURCHES

In continuing the dialogue we find the following points are important:

1. **Nuclear Energy and Social Goals.** Further discussion of the technicalities of nuclear energy should take place in a framework showing the relation to structural change and social justice, which implies a discussion of social goals and what constitutes progress. There is a tendency especially in the discussion of energy options to take as given the present emphasis on economic and energy growth in society. In this situation technological developments, like nuclear energy, tend to govern social ends so that social structures are inclined to conform to the dictates of technology. This problem should be one of the main foci of further ecumenical consideration of nuclear energy. This would be an especially fruitful theme for a continuing dialogue between natural scientists, technologists, theologians and social scientists, and political decision-makers.

2. **Nuclear Energy and the Distribution of Techno-Political Power.** The report raises the question of the impact of nuclear energy in increasing the disparity between the developed and the developing parts of the world. The concern for social justice and solidarity should lead us to press for a more equal distribution of techno-political power in the world. This issue requires immediate concern lest the expansion of nuclear energy increase these disparities. Moreover nuclear scientists tell us that international collaboration is the only realistic basis for a safe nuclear energy programme. What is entailed in the development of such a programme?

3. **The Ethics and the Method of Choosing Between Alternatives.** We have to make choices between different forms of energy supply. All alternatives must be studied and the same set of criteria applied to each before any choice is made. Yet in making the choice it is never possible to be absolutely sure about the right decision, e.g. it is impossible to eliminate all risks, or even to know exactly how great the risk may be. All human decisions are necessarily based on such imperfect and fallible knowledge. We are justified in demanding the most accurate possible knowledge of the advantages, risks and hazards of nuclear power, and also of the alternatives. Unique ethical problems may arise from the hypothetical nature of risk estimation with large-scale nuclear energy.

4. **The Limits of Technical Analysis.** While technical study can supply information on the risks and hazards of nuclear power, it cannot provide all the criteria by which these should be judged. A different kind of study is necessary to choose these additional criteria, and here we run into the difficulty that value systems vary between individuals and peoples. Criteria are needed to deal with such questions as:

- the evaluation of risks to future generations;
- the shape desired for society, or societies, in the future; (What values will shape those societies?)
- how to distinguish needs from wants in a society?
- the social structures of surveillance required by nuclear energy systems, and their consequences at the political level. (Who finally decides and how?)

5. **Theological Critique of the World View Implied in the Nuclear Choice** (and by implication of the choice already made for a technological civilization). This world view involves an act of faith in humanity that it will be able intellectually, technically, psychologically, morally and spiritually, to master the awesome possibilities of nuclear power. The nuclear option implies a high level of discipline on the part of all people. It also requires a realistic assessment of the need for checks and balances necessary to minimize the effects of human folly and sin. On what assumptions is this faith credible? How far does it rely too much on human rationality, efficiency and achievement orientation?

6. **Rethinking the Faith Perspective.** The nuclear situation deepens the questioning of the presuppositions and goals of contemporary technological civilization, and the dilemmas posed by its achievements and its weaknesses become inescapable. It also brings us to such fundamental questions as: (i) How can men cope with their creativity? (ii) How can they live together in their diverse societies in a tolerable harmony? (iii) How far are they responsible for future generations? The Christian will want to seek help from his faith on these and other issues. A central message of the gospel is to respond to the coming of Jesus Christ by seeking God's kingdom and his righteousness, to live one's life in a joyful freedom from anxiety, not distraught by fears of the future, and looking with a sure hope that what God has begun in Christ he will complete in "a new heaven and a new earth". While in the gospel this confidence for living from day to day is set in a very limited human time perspective, in essence this confidence is the same now although our time perspective is immeasurably lengthened. But what precisely does this mean for human planning for the future? How far do recent scientific developments oblige us to reassess the whole scientific revolution from the 17th century out of which the harnessing of the powers of the universe which dominate our thoughts today has come? Is man "playing God", or is he grasping creative techniques which God intends him to use responsibly? As humanity's scientific and technical capabilities increase, so do the stakes involved in its decisions become greater. The scale of success and failure becomes more dramatic. How far should the risks be run? How far would drawing back be a faithless failure of nerve? When is it necessary to say no in the name of God to something which is technically possible but which would be a betrayal of humanity to do?

All these different questions still have to be dealt with, in specific terms, and altogether, as part of the wider understanding of reality. Dialogue on such issues between Christians, with persons of other faiths, and with all persons of good will, has therefore to continue. The churches, and the World Council of Churches, are still just beginning to grasp the opportunity for probing the religious and ethical mysteries posed by a nuclear age. Attempting the challenge, in faith, they might still be a light to themselves and their world which is in deep spiritual confusion.

VII. SOME CONCLUSIONS

This Hearing has been a valuable experience to all participants. It has shown both the importance and the feasibility of a dialogue between people with widely differing backgrounds, coming from many different countries, but all of them seriously concerned about the problems nuclear energy may solve or create. It has given a wonderful opportunity to exchange views and to test, to widen or to correct personal opinions. We are pleased to share the results of our discussion with all those interested and involved in these questions. We hope it will offer some guidance to those who will have to make up their mind on these difficult issues. The rapid growth and increasing complexity of knowledge increases the need for this kind of interdisciplinary dialogue.

The Hearing has also left many of us in a state of perplexity, as we came to realize the meagreness of our knowledge and the momentousness of the decisions the world has to take. The presence among us of foremost experts in several branches of nuclear science and technology has not removed this uneasiness. No government, no organization, no individual can shirk responsibilities by referring simply to expert knowledge, for no one can be expert on all the physical, technical, geological, medical, biological, economical, social and political aspects of the nuclear issue. Weighing and synthesizing the opinions of many different experts and sifting the enormous amount of data available in published reports, tables, monographs and textbooks requires an "expertness" of a higher order. Therefore our group cannot put forward categorical recommendations. **It would not feel justified in either entirely rejecting, nor in whole-heartedly recommending large-scale use of nuclear energy.** All the same we can put forward some conclusions and outline some areas where our appraisals diverged.

1. We have been impressed by the reports on the safety of reactors. We are convinced of the deep sense of responsibility of many of those who design and operate nuclear reactors, and we are willing to concede that a nuclear power station operation in a stable world does not present greater risks than many chemical plants we have so far accepted without much misgivings. (Some of us may have even begun to worry more about such plants and about the vulnerability of our technological society in general than about nuclear reactors.) We have every reason to believe that at least comparable attention is being paid to the safety aspects of the fast breeder reactors which are being tested and which are potentially more dangerous. From this point of view there is no reason to draw the line between "burners" and "breeders"; there may, however, be other reasons for doing so.

2. Not all of us were aware of the fact that little reprocessing of spent nuclear fuel has as yet been taking place. The nuclear energy delivered thus far stems mostly from the fission of uranium 235; the plutonium fuel cycle is not yet in full swing. Even without plutonium extraction, nuclear reactors can produce nuclear power at comparable cost: this is shown by the Canadian example. But if we continue to work that way the world reserves of cheap uranium will soon be exhausted. Nuclear reactors without fuel reprocessing can therefore provide only a temporary solution: they can help to bridge a gap until other energy sources become available; they do not offer prospects for a long lasting solution of the world's energy problems. Some people would be willing to accept nuclear energy, but only as a limited interim solution. They would therefore be against fast breeders, for fast breeders have been developed to use the plutonium recovered from the spent fuel. Those who would in principle be willing to accept a fuller nuclear programme, but who favour a very cautious progress will have felt relieved by the statement that breeders will not be commercial before 1990. This seems to assure that there will be much more research and testing before they come into widespread use.

3. Speaking of the hazards involved in a large-scale worldwide nuclear programme the American nuclear scientist Alvin Weinberg, has said: "The price we demand of society for this energy source is both a vigilance and a longevity of our social institutions that we are quite unaccustomed to." This statement was endorsed by most members of our group, but opinions differed widely as to the chances for such conditions being realized.

There are those who fear that the required vigilance will in the long run only be possible in an authoritarian society.

Those who are inclined to doubt the possibility of such vigilance and longevity, have either to reject nuclear energy entirely or to accept it only in a severely limited form, i.e. they might accept nuclear reactors without reprocessing and only in locations where favourable conditions for permanent storage of spent fuel exist. This would in no way obviate the need for vigilance with respect to wastes, but the dangers of plutonium theft at (or on the way to or from) reprocessing plants would disappear.

Others believe that the existence of large-scale nuclear energy will force countries to come together and that it will have a stabilizing and pacifying influence. Finally still others believe that the world is well-prepared for large-scale nuclear energy and that adequate security measures exist.

4. The position of developing nations received special attention. Some nations – e.g. India, Brazil, Argentina – have embarked upon extensive nuclear energy programmes. On the other hand, the economies of most of the African countries are not at present prepared to distribute and use the large quantities of electric power produced in a nuclear power station. For the time being more dispersed conventional power units of smaller capacity seem practical to meet the needs of the prevailing economy.

It was the opinion of many that nuclear energy will give the nuclear nations too much technological control over the developing countries as they accept technical assistance in the nuclear field; and the possible influence of large industrial firms on the nuclear economics and politics of such countries was viewed with alarm. (This situation might change as developing countries themselves become exporters of nuclear technology.) The Non-Proliferation Treaty was not acceptable to everyone, especially to those who considered that it interfered with the independence of a country; and some rejected the very idea of a treaty that recognizes the right of a few countries to make and possess nuclear weapons, while at the same time seeking to prevent other countries from doing the same.

There was a wide spread of opinions as to whether nuclear energy might possibly be of use to developing countries: some members were convinced that it will be an invaluable aid in fighting famine and misery, while others denied its potential usefulness altogether. All of us agreed that it will be of no avail without a more equitable world economic order.

5. It is regrettable but inevitable that one cannot speak about nuclear energy without thinking about nuclear weapons.

For the nuclear nations, the former may be considered a spin-off of the latter; the armaments programme in these countries will hardly be influenced by the existence or non-existence of power producing reactors. For other countries the situation may be just the opposite: nuclear weapons will be a spin-off of nuclear energy. Certainly it is a political decision to make nuclear bombs, but it will be much easier to carry out this decision if there already exists a general competence in nuclear technology.

So far the existence of nuclear weapons may have contributed to the avoidance of a Third World War. Will this continue to be the case when more and more countries possess nuclear weapons? All of us are deeply convinced that a peace based on nuclear deterrence is at best precarious.

It is not that kind of peace we are longing for, when we read in the gospel about peace on earth.

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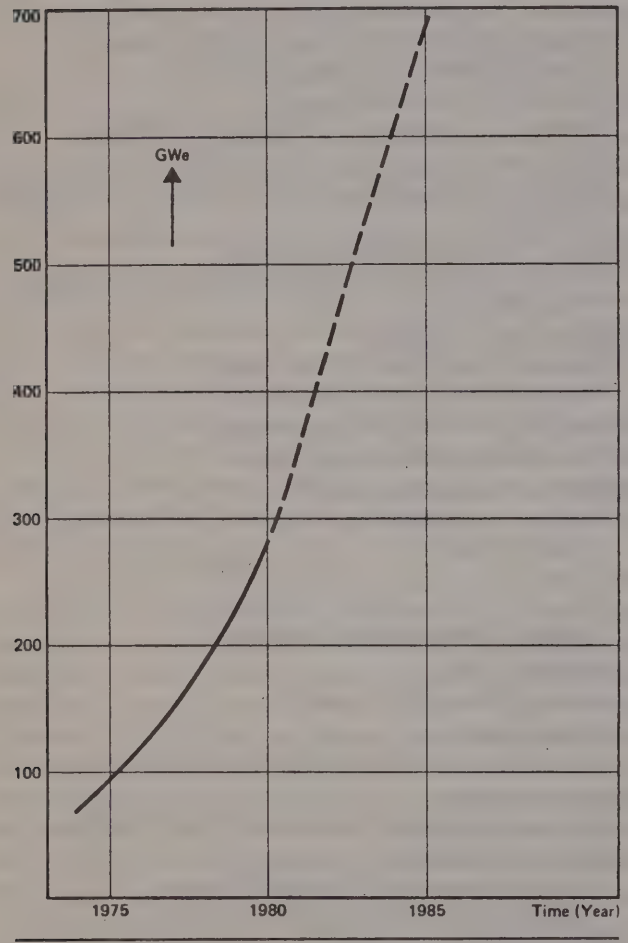
APPENDIX A

PRESENT SITUATION REGARDING THE PRODUCTION OF ELECTRICITY BY NUCLEAR POWER PLANTS

According to a recently published statement by staff of the International Atomic Energy Agenca*, the forecast of the world's nuclear electrical power in the period 1975-1985 is presented in Figure 1. The section of the curve up to 1980 represents the aggregate picture that has been assembled from governmental information on nuclear power plants that are currently in operation, under construction and planned for completion during this period.

FIGURE 1

FORECAST OF THE WORLD'S NUCLEAR ELECTRICAL POWER IN THE PERIOD 1975-85



The growth of production capacity in the period 1980-1985 is obviously dependent on the availability of power plants which are now in the planning stage and for which a firm construction schedule is still to be finalized. The number of nuclear fuel cycle facilities to come into operation during the decade 1975-1985 is also presented in Table 1, and it is evident that in addition to a fourfold increase in the number of power reactors, there is virtually a doubling in the requirement for each stage of the fabrication, enrichment and reprocessing cycle in support of the expanded reactor programme. Since the specific reactor types are already known for most of these programmes, it is also possible to calculate the inventory of nuclear materials used for their operation. The divergence in the utilization of low enrichment uranium oxide based fuels as compared with natural uranium is indicative of the heavy commercial penetration of the world market by light-water reactor designs, similar to those adopted in the U.S.A. (Figure 2). The

TABLE 1

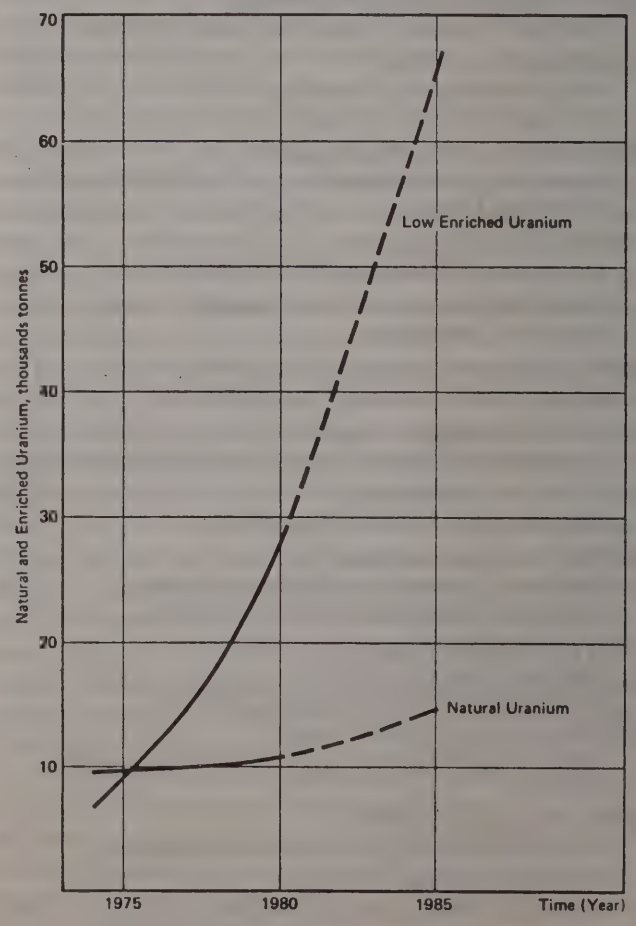
NUMBER OF FACILITIES IN THE NUCLEAR FUEL CYCLE

TYPE OF FACILITY	1975	1977	1980	1985
POWER REACTORS	200	280	420	800
URANIUM FUEL FABRICATION PLANTS	24	28	36	55
URANIUM AND PLUTONIUM MIXED OXIDE FUEL FABRICATION PLANTS	21	23	26	30
IRRADIATED FUEL REPROCESSING PLANTS	6	8	12	17
ENRICHMENT FACILITIES	8	9	10	13

rate of plutonium production based on present operational experience with power reactors has also been calculated; the plutonium inventory associated with the reactor programmes is shown in Figure 3 for both thermal and fast reactors and includes the cumu-

FIGURE 2

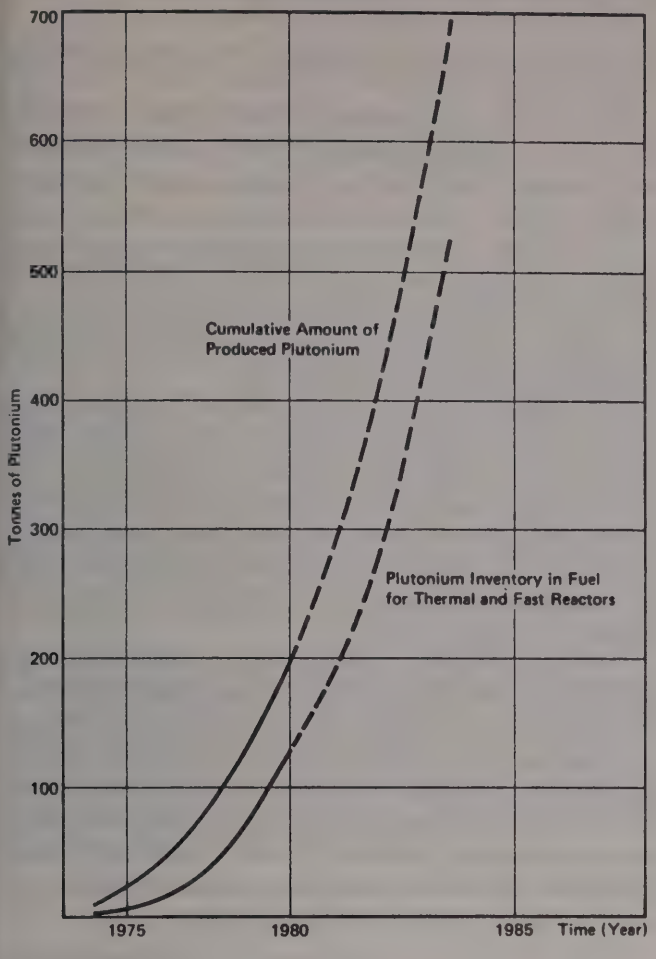
INVENTORY OF NATURAL AND ENRICHED URANIUM IN POWER REACTORS



* *Bulletin* International Atomic Energy Agency, Vol. 14, no. 2, April 1975, pp.4-14.

FIGURE 3

CUMULATIVE AMOUNT OF PRODUCED PLUTONIUM AND INVENTORY OF PLUTONIUM IN FUEL FOR THERMAL AND FAST REACTORS



lative amounts of plutonium in the spent fuel of thermal reactors. In some countries, the plutonium has not yet been extracted from the irradiated fuels but has simply been stored prior to the start of reprocessing; this is part of the Canadian policy with natural uranium fuels.

It is also worth describing the developing situation in terms of the positions that countries have adopted or are now adopting in relation to the prospect of expanding nuclear power programmes. At least these categories can be easily identified:

1. Countries which have nuclear power reactors in operation

These countries are listed in Table 4, which summarizes the position at the end of 1974. It can be seen that most countries have as yet made only a relatively small commitment to nuclear power generation, although there are substantial programmes of nuclear research under way in nearly all of these countries. The transition that will take place during the period 1974-1980 is already quite dramatic as a significant number of countries, particularly in Western Europe, anticipate a threefold increase in the installed nuclear generating capacity.

2. Countries which plan to introduce nuclear power in the near future

Some countries have been included in Table 4 because they have definite plans to introduce nuclear power by the year 1980, viz. Austria, Brazil, Finland, Hungary, South Korea, Mexico, Taiwan, Thailand.

There are in addition other countries which plan to have nuclear power reactors in operation in the next decade, although firm commissioning dates have yet to be announced: Denmark, Iran, Israel, Philippines, Poland, Romania, South Africa, Yugoslavia.

3. Countries without plans for nuclear power plants

There are many countries, particularly in Africa, Latin America and Asia, which for technical and economic reasons have no plans to introduce nuclear power plants. These reasons include: small sizes of the power grid, sufficient supplies of other energy sources and lack of the required scientific and technical infrastructure.

TABLE 4

Countries which have nuclear power reactors in operation and have planned additions to installed capacity

Country	Number of Power Reactors* 1974	1975	1980
Argentina	1	1	2
Austria	–	1	1
Belgium	1	2	3
Brazil	–	–	1 (8)**
Bulgaria	1	2	4
Canada	7	6	12
Czechoslovakia	1	1	5
Finland	–	–	3
France	9	11	23 (1)
Germany, Dem. Rep.	2	3	3
Germany, Fed. Rep.	10	10	28 (4)
Hungary	–	–	1 (1)
India	4	3	8 (2)
Iran	–	–	– (4)**
Italy	3	3	7 (1)
Japan	10	11	29 (3)
Korea, South	–	–	2 (1)
Mexico	–	–	2
Netherlands	2	2	2
Pakistan	1	1	1
Spain	3	3	11 (2)
Sweden	4	5	11 (1)
Switzerland	3	3	8 (4)
Taiwan	–	–	4
Thailand	–	–	1 (1)
USSR	16	16	24
UK	31	31	39
USA	60	69	156 (37)
Total	169	184	391 (58)

Sources: 1974 and 1980 – The Nuclear Age, *SIPRI, 1974.*
1975 – *"World List of Nuclear Reactors", in* Nuclear News, *18/10, p. 63, Aug. 1975.*

* Output greater than 20 MW(e); the number in brackets after the 1980 figure is that of planned reactors not under construction on 1 January 1975

** Corrected according to latest newspaper reports.

APPENDIX B

NON-NUCLEAR ENERGY PROGRAMMES FOR DEVELOPING COUNTRIES

Electrical requirements of many developing countries in Africa, Asia and Latin America are still modest, and for technical and economic reasons will be met by small production units, for some time to come. Many of these countries have not reached the level of economic and industrial development to afford and support the introduction of nuclear energy installations. Neither do they have a nucleus of trained skilled personnel to help in the maintenance, operation and supervision of these installations. Furthermore, these countries lack the requisite organizational and institutional structures for the running of complex installations such as nuclear electricity generating installations including reprocessing plants and waste disposal systems or procedures. A large proportion of the population in these countries resides in the rural areas, where the consumption centres are relatively dispersed, and thus call for more decentralized supply systems.

It is in the interest of these countries to undertake a systematic survey and inventory of indigenous resources in order to enable them to plan the most suitable ways and means of meeting their energy requirements in the foreseeable future. In this context mention should be made of the prevalance of energy sources such as hydro, coal, natural gas, petroleum, oil shale, geothermal energy, solar energy, tidal and bio-conversion of plant and animal waste, etc.

Of these, bioconversion offers the greatest promise and should be given more serious attention. It can provide energy as well as fertilizers, although the deployment of this system of energy conversion may be limited by the availability of water resources. Solar energy is abundant in most of these areas, but it suffers from certain techno-economic as well as cultural limitations that must be overcome if its widespread utilization is to become a reality.

Better conservation procedures as well as more efficient and effective use of existing installed electricity generating capacity in these countries is also called for. In addition, it is in the interest of many of them to cooperate in the joint development of hydroelectricity in order to share the high initial capital costs and ensure an adequate market; in the search for new deposits of coal, oil and natural gas; in adopting measures (with oil producing countries) that would guarantee the supply of petroleum and its products under commonly acceptable conditions, etc.

In the longer run, there may be scope for the introduction of nuclear plants into the power systems of these countries, when a sufficiently large number of them will have systems large enough to absorb nuclear plants. The countries will also be on a stronger industrial and economic footing which will enable them to support a nuclear electricity generating installation and have the technical and organizational capacity to maintain, operate, supervise and manage such complex systems.

There are, of course, countries in Africa which already have large enough power systems and an adequate economic and industrial base to support a nuclear energy installation including fuel processing plants. It is hoped that in their deliberations and decision on the nuclear option these countries will take into account the availability and supply of other sources and forms of energy, the costs and benefits of these and the safety requirements and environmental and social-economic consequences of whatever option – nuclear or non-nuclear – is decided upon.

APPENDIX C

SUMMARY OF RESEARCH AND DEVELOPMENT OF ENERGY RESOURCES

The position concerning future prospects has been ably summarized in a recent O.E.C.D. report (Energy R / D: Problems and Perspectives, Paris 1975); the main results relating to the more promising and realistic solutions are as follows:

The short-term (1974-1985)

In the short term, energy needs will be satisfied mainly by the same resources and technologies as exist today. Nevertheless, R & D activities, and more particularly those which already exist, can make significant contributions by discovering new resources and by improving existing technologies.

(i) **Oil and natural gas** will continue to play a major role. Among the most important possible contributions of R & D are:
- the improvement or prospection technologies on and off-shore;
- the improvement of secondary and tertiary recovery methods;
- better deep-drilling technologies;
- with regard to off-shore technologies, it should be possible to produce oil in increasingly deep waters, up to an ocean depth of approx. 1,000 m.

(ii) **The direct use of coal for electricity generation** will probably become more extensive. The most relevant contribution of R & D in this sector will be the development of new stack-gas cleaning technologies.

(iii) **Nuclear energy for electricity generation** will be developed very rapidly. This development will essentially be based on already existing reactor types; mainly light water reactors and to a much smaller extent, heavy water reactors. In the nuclear energy sector, the greatest part of the R & D effort will have to focus on the fuel cycle.

Several energy sources could make contributions which, though limited in overall terms, might be quite significant in specific cases, for example:
- shale-oil in-situ extraction in the United States;
- tar-sand oil extraction in Canada;
- geothermal energy through dry steam;
- solar energy for space heating and cooling;
- synthetic fuels through pyrolysis of organic waste.

As to **energy carriers,** it is probable that electricity technologies will develop most rapidly. R & D will continuously improve

the efficiency of electricity generation and reduce thermal pollution problems, through cooling towers, increasing utilization of the residual heat of power plants, etc.

Finally, the analysis of **energy systems** should be pursued with greater speed and scientific effort. The contribution of systems analysis to a rational and efficient solution of energy problems could certainly make itself felt in the short term, but it is also important for the medium and longer term.

The medium-term (1985-2000)

R & D now being pursued will have a much broader impact in the medium than in the short term. With regard to energy resources, it should be possible to produce **oil** from an **ocean depth** of considerably more than 1,000 m, and **tertiary recovery methods** will probably be applied on a broad, general scale. Better **coal conversion** (gasification, liquifaction, conversion into methanol), and advanced **coal firing** technologies will confirm the importance of coal for electricity generation and for synthetic fuel production. In addition, **shale-oil** extraction could spread to many countries which hitherto have made no systematic effort to discover and assess shale resources. Finally, **nuclear energy** will occupy an increasingly important place, following the introduction of **fast-breeders** and of **high temperature gas cooled reactors.**

Again, certain **non-conventional energy sources** could play a globally limited but locally very important role. Among these sources are geothermal energy through hot brines, solar energy for electricity generation, synthetic fuels through bio-conversion of plants or organic waste, wind-power, etc.

Electricity will probably remain the energy carrier with the fastest development potential. Electricity generation could benefit from progress in advanced cycles and perhaps fuel cell technologies, electricity storage from progress such as that made with batteries and electricity transmission from that with underground cables. Moreover, electricity will profit from increasing possibilities of application such as electric cars. Other energy carriers will become increasingly important, for example methanol or others which can store and transport heat in the form of chemical bond energy.

It is in the medium term that research to improve **energy utilization** will be most successful. A more efficient energy utilization at the level of individual technologies might help considerably to slow down the growth rate of energy demand.

The long-term (after 2000)

The long-term prospects are obviously much more uncertain. **Fossil fuels** will continue to play a noteworthy role, especially **coal,** as coal reserves are known to be sufficient for several centuries at the present rate of consumption. However, progressively, fossil fuels will have to give way to energy sources which have, if not "unlimited", then at least extremely abundant reserves. Thus, in the very long term, fast breeders, controlled thermonuclear fusion, solar energy and last, perhaps geothermal energy through hot rocks will increasingly replace present energy sources.

As far as **energy conservation** is concerned, the biggest long-term impacts of R & D will among others, be found in the transportation and agricultural sectors.

APPENDIX D

SWEDISH OPINION POLLS ON NUCLEAR ENERGY

In Sweden after a nation-wide information campaign supported by government money, several polls were made during the spring. Some of these were carried out within the five political parties with representation in the Swedish parliament. In addition to a choice between various alternatives regarding nuclear energy the persons interviewed were asked about their opinion on the energy consumption in general. As an example of the results obtained in these polls we quote the following ones which date from March of this year. They pertain to people who voted for the social democrats (the government party) in the last election.

No nuclear energy at all	26%
Nuclear energy as a last resort	37%
Nuclear energy is necessary for keeping our standard of living	18%
Uncertain	19%
Total	100%

On the question of the energy consumption in general the following answers were given:

Energy consumption should be kept constant	37%
Energy consumption could decrease	36%
Moderate increase recommended	19%

As a final remark it may be mentioned that a decision in principle has been made (as of June 1975) to build 13 reactors in Sweden on four different sites totalling an effect of approx. 10,000 MW(e) which would imply a fraction of about 10% of the total energy production coming from nuclear power plants. Of the total electric power 30-40% would be nuclear when the programme is completed (around 1985). The nuclear energy programme will be reviewed again in 1978, using the experience gained in the meantime both within Sweden and abroad.

ENERGY OPTIONS AND THE ROLE OF NUCLEAR ENERGY IN ASIAN COUNTRIES

K.T. THOMAS

I propose in this paper to analyze energy production and consumption patterns in the Asian countries, their minimum needs for attaining a barely satisfactory standard of living, the gap between the two, and how alternate sources of energy including atomic energy have to be seriously considered in bridging this gap. The countries covered are:

1. Middle East including Egypt, Iran and Turkey
2. India
3. Pakistan, Burma, Sri Lanka
4. Indonesia, Singapore, Malaysia and the Philippines
5. Thailand, Laos, Khmer Republic, Republic of Vietnam
6. Republic of South Korea
7. Japan

These countries vary a great deal not only from the point of view of energy consumption. In a paper like this it is not possible to cover all the aspects in full, but one can only try to do a macro-analysis of the situation and paint the scenario with a broad brush.

Table I gives details of per capita national income in US dollars and per capita energy consumption in kgs. coal equivalent, of principal Asian countries compared with Europe and North America. The data have been collected from the latest information available and are applicable mostly to the years 1970-72. It is recognized that after the oil crisis in 1973, the situation has changed radically and therefore, the data may need considerable updating. The general analysis, however, will not show any appreciable change in trends. The per capita national income varies from a low US $ 68 (1969) for Burma to US $ 3700 (1971) for Kuwait, whereas the average figures of USA and Canada combined was US $ 5000 in 1972 with the world average at US $ 930 in 1970. The lowest figure was thus about 1/75th of the US per capita income, 1/40th of Western Europe and about 1/14th of the world average. The basis for considering whether a country is developed or not has been discussed on many occasions in the past but no universally accepted guidelines exist. The status of a country can be gauged by the standard of living of its people as compared with that which can be sustained by production based on the present level of science and technology. The per capita national income of the world is sometimes regarded as an appropriate dividing line to consider whether a country is developed or not. With the exception of Burma, India and possibly Laos and Khmer Republic most of the other countries in the region have an average per capita national income which varies between US $ 160 to 500 with an approximate average of US $ 275. Since energy is an input to all productive operations there is a correlation with per capita national income i.e. the more the national income, the more energy is consumed per capita. Though this need not exactly be correct as the size and population vary in each country, the per capita consumption of energy is still one of the best available criteria for judging the degree of development of a country.

Due to lack of availability of data, China and a few of the other countries in the region have not been included in the study. Some of the countries are very highly populated as for example India with about 560 million people (1972).

Table II gives the population of the countries, the total electricity production, the total consumption of commercial source of energy and the per capita energy consumption in kgs. coal equivalent.

Excepting Japan, Singapore and Middle Eastern countries the rest of the countries, with a total population of about 1000 million, have an average energy consumption of only about 200 kgs. coal equivalent. The population density per square kilometre varies in these from a low 4 to as high as 3700 but most of the countries are below 100. The per capita energy consumption of the world average of about two tons of coal equivalent is half that of Western Europe and about 1/6th of that of USA and Canada. The world average is about 10 times the Asian average (with the ex-

Table I
Energy Consumption Vs National Income

S.No.	Country	Per capita National Income (US dollars)	Per Capita Energy Consumption (kgs. coal equ.)
1.	Kuwait	3703 (1971)	10,441
2.	Japan	2462	3,251
3.	Israel	2007	2,712
4.	Singapore	1041 (1971)	885
5.	Lebanon	521 (1970)	889
6.	Malaysia	391	491
7.	Iran	367 (1971)	954
8.	Turkey	335 (1971)	564
9.	Syria	295 (1971)	455
10.	Republic of Korea	281	827
11.	Iraq	278 (1969)	642
12.	Jordan	276	331
13.	Philippines	254	311
14.	Saudi Arabia	*	900
15.	Pakistan	205 (1971)	158
16.	Egypt	202 (1970)	324
17.	Thailand	193	305
18.	Rep. of Vietnam	174 (1971)	287
19.	Sri Lanka	164 (1971)	146
20.	Khmer Republic	*	25
21.	Indonesia	112	133
22.	India	91	186
23.	Burma	68 (1969)	58
24.	Laos	*	79
25.	Bangladesh	–	32
26.	World	930 (1970)	1,984
27.	USA & Canada	5000	11,526
28.	Europe (except Eastern)	2740	4,000

Source: U.N. Statistical Yearbook 1973

All the figures unless otherwise indicated are for 1972.

* Figures are available for these countries only upto the year 1963. They are:

Saudi Arabia	230
Khmer Republic	117
Laos	61

ception of Japan, Singapore and the Middle Eastern countries).

In order to assess the gap in the energy requirement and the need and scope for atomic energy, it is necessary to aim at a minimum requirement which it is desired to achieve. Since there is no known absolute criteria to guide us, we have to make certain assumptions in setting up this goal. One extreme way of looking at it is to hope for a target achievement of consumption in North America. Alternatively, one could set the Western Europe average or the world average as the goal. For the purpose of this paper, we may assume that the developing countries need a per capita energy consumption of about 4 tons of coal equivalent, i.e. of 32 MWh energy per capita per annum which was Western Europe's per capita average for 1972. The present level in Western Europe, is much above this figure already. (Even though the target of per capita energy requirement is put at 4 tons of coal equivalent, it is based on 1972 population figures. By the time actual increase in energy production takes place, the population would have increased considerably. For example, by the year 2000 it is expected that the population would almost be double the 1972 figure, which means that the per capita energy requirement of 4ßtons set now would effectively be only about 2 tons coal equivalent. This is the present world average.)

Table III gives data regarding known reserves of solid, fluid and hydro power available in Asian countries. The per capita energy consumption of 32 MWh per annum is very much higher than the hydropotential available which cannot contribute anything but a small fraction of the total energy requirements. The energy, therefore, has to come from coal or oil. Excepting Saudi Arabia, Kuwait, Iraq and Iran, in the countries for which information is available, to meet the minimum energy requirements of 32 MWh the reserves will last for only a limited number of years. For example, India would have exhausted its resources in approximately 50 years, Pakistan in about 11 years, Burma in one year, Indonesia in 8 years, Japan in 46 years and the rest of the countries in about 10 years or less. Kuwait has reserves to last, if consumed for their own needs, for about 4650 years, Saudi Arabia for about 920 years, Iraq about 185 years and Iran about 175 years. If the average of all the countries is taken, and if the reserves are used only between themselves, then it will not last for more than 50 years. But the above analysis is misleading, in the sense that the Middle Eastern countries as major oil producing countries are meeting the demand of most of the countries in the rest of the world and it is practically impossible for the Asian countries to spend their resources only among themselves. If one takes solid fuels only, the picture is still worse. The resources in the region are expected to last less than 30 years. This also does not give the real picture as the solid reserves available are located only in five or six countries and there is a minimum production capacity possible as will be shown later. Also, the question of transport and intercountry co-operation is involved.

Table II

POPULATION, ELECTRIC ENERGY PRODUCTION AND TOTAL ENERGY CONSUMPTION

S.No.	Country	Population ('000)	Density of population (per km^2)	Total elect. production (10^3 MWh.)	Total energy consumption (10^6 tons coal equ.)	Per capita energy consumption (kg. coal equ.)
1.	India	563494	172	66385 (1971)	104.82	186
2.	Pakistan	56065	70	7449 (1971) P	9.66	158
3.	Burma	28885	43	654 P	1.66	58
4.	Sri Lanka	13033	199	995	1.91	146
5.	Bangladesh	53209*	—	920 P	2.40	32
6.	Indonesia	121630	82	2368 (1971) P	16.13	133
7.	Singapore	2147	3695	3144 P	1.90	885
8.	Malaysia	10910	33	3545 (1970)	5.66	491
9.	Philippines	39040	130	8666 (1970)	12.15	311
10.	Japan	106958	287	428577	344.55	3251
11.	Thailand	36286	71	5225 (1971)	11.05	305
12.	Laos	3106	13	64	0.24	79
13.	Rep. of Vietnam	15317*	–	1483	5.48	287
14.	Khmer Republic	5838*	—	1656 P	0.18	25
15.	Egypt	34839	35	8030	11.29	324
16.	Iran	30550	19	9100	29.14	954
17.	Turkey	37000	47	11242	20.88	564
18.	Saudi Arabia	8199	4	1000 P	7.38	900
19.	Kuwait	914	51	3295 P	8.77	10441
20.	Iraq	10074	23	2261 (1971) P	6.46	642
21.	Jordan	2467	25	249	0.82	331
22.	Israel	3080	149	8478	8.35	2712
23.	Lebanon	2963	285	1545 P	2.64	889
24.	Syria	6673	36	1223	3.04	455
25.	Rep. of Korea	32360	329	12697	26.76	827
26.	World	3,782,000	28	5646,700	7408.68	1984
27.	Europe (excluding Eastern)	364,000	92	1295,832	1435.75	4000
28.	USA & Canada	230,690	11.9	2091,017	2659.80	11526

Source: U.N. Statistical Yearbook 1973

NOTE: 1. All the figures are for the year 1972 unless otherwise stated.
2. P: for sale purpose, does not include power generated by the industries for their own use.
3. * Figures are for 1963.

Table III
ABSOLUTE RESERVES OF COAL, LIGNITE, PETROLEUM, NATURAL GAS, HYDRO-POWER AND PER CAPITA RESERVES

S.No.	Country	Population (million)	Total Solid Fuels (10^6 MWh.)	Total Fluid Fuels (10^6 MWh.)	Total Solid & Fluid Fuels		Water Power	
					(10^6 MWh.)	Per capita (MWh.)	10^6 MWh/year	Per capita/year (MWh.)
1.	India	563.5	855237	1546*	856783	1520	320	0.56
2.	Pakistan	56.1	13988	5858	19846	354	***	***
3.	Burma	28.9	830	92	922	32	–	–
4.	Sri Lanka	13.0	–	–	–	–	11	0.84
5.	Bangladesh	53.2	–	–	–	–	***	***
6.	Indonesia	121.6	11760	19245	31005	255	0.81 (1966)	0.01
7.	Singapore	2.1	–	–	–	–	–	–
8.	Malaysia	10.9	–	2352	2352	216	5.36 (1967)	0.53
9.	Philippines	39.0	220	–	220	6	15.1 (1967)	0.38
10.	Japan	107.0	158396	121	158517	1481	131.9 (1967)	1.23
11.	Thailand	36.3	587	–	587	16		
12.	Laos	3.1	–	–	–	–	60.0**	1.00
13.	Rep. of Vietnam	15.3	–	–	–	–		
14.	Khmer Republic	5.8	–	–	–	–		
15.	Egypt	34.8	–	7517	7517	216	15.0 (1960)	0.43
16.	Iran	30.5	8000	162134	170134	5578	–	–
17.	Turkey	37.0	15382	335	15717	425	57 (1967)	1.54
18.	Saudi Arabia	8.2	–	240220	240220	29295	–	–
19.	Kuwait	0.9	–	133918	133918	148797	–	–
20.	Iraq	10.1	–	59196	59196	5861	–	–
21.	Jordan	2.5	–	–	–	–	–	–
22.	Israel	3.1	–	11	11	4	–	–
23.	Lebanon	3.0	–	–	–	–	–	–
24.	Syria	6.7	–	2184	2184	326	–	–
25.	Rep. of Korea	32.4	9492	–	9492	293	16.0+	0.5

Sources: *i) World Power Conference: Survey of Energy Resources 1968*
ii) U.N. Statistical Yearbook – 1973

All the figures are for the year 1972 unless otherwise stated

For the countries where no figures are given, either the hydro-resources are non-existing or very minor

* Present indications are that the actuals may be much higher

*** Only combined figures for Thailand, Laos, Rep. of Vietnam and Khmer Republic available.

*** Figures not available separately for Pakistan and Bangladesh

\+ Estimated from information given in the Proceedings of the Conference on the "Peaceful Uses of Atomic Energy" – Vol. I, 1971.

Conversion factors:

1 ton coal	8,000 KWh.
1 ton lignite	2,500 KWh.
1 ton petroleum	12,000 KWh.
1 m^3 natural gas	10.6 KWh.

Table IV
COAL AND LIGNITE RESERVES AND ANNUAL PRODUCTION FOR MAJOR COAL PRODUCING COUNTRIES

S.No.	Country	Population (million)	Coal & Lignite Reserves (10^6 T.C.E.)	Annual Production		Per capita Energy Consumption (Kg.C.E.)	% Contribution of coal production to energy consumption
				Total (10^6 T.C.E.)	Per capita (Kg.C.E.)		
1.	U.S.S.R.	247.4	4,561,097	498.7	2015	4767	42.2 E
2.	China	800.7	1,011,220	400.0	500	–	– –
3.	U.S.A.	208.6	1,226,875	537.0	2571	11611	22.1 E
4.	India	563.5	106,900	75.7	134	186	72.0 E
5.	W. Germany	61.6	89,375	137.2	2227	5396	41.2 E
6.	Poland	33.1	50,385	162.6	4912	4556	107.8 E
7.	Australia	12.9	45,875	56.3	4364	5701	76.5 E
8.	U.K.	55.8	15,500	119.5	2141	5398	39.6 E
9.	Japan	107.0	19,790	28.0	261	3251	8.0 I
10.	France	51.7	2,810	30.6	591	4928	12.0 I
11.	Belgium	9.7	1,796	10.5	1082	6468	16.7 I

Source: UN Statistical Yearbook 1973.

* *Based on the assumption that the coal production is used entirely for internal consumption and there is no export*

T.C.E.: Tons Coal Equivalent
Kg. C.E.: Kilogram Coal Equivalent
E indicates exporting countries
I indicates importing countries

Table V
COAL AND LIGNITE RESERVES AND ANNUAL PRODUCTION

S.No.	Country	Coal & Lignite Reserves (10^6 T.C.E.)	Annual production* (10^6 T.C.E.)	Years of exhaustion if coal's share in per capita energy requirement is 1 T.C.E.	2 T.C.E.	3 T.C.E.	4 T.C.E.	Export or import
1.	India	106905	75.90	190	95	63	48	E
2.	Pakistan	1748	1.25	31	16.5	10	8	I
3.	Burma	104	0.016	3.6	1.8	1.2	0.9	I
4.	Sri Lanka	–	–	–	–	–	–	–
5.	Bangladesh	–	–	–	–	–	–	–
6.	Indonesia	1470	0.18	12	6	4	3	–
7.	Singapore	–	–	–	–	–	–	–
8.	Malaysia	–	–	–	–	–	–	–
9.	Philippines	27	0.04	0.7	0.35	0.2	0.2	–
10.	Japan	19790	28.02	185	92.5	62	46	I
11.	Thailand	73	0.10	2	1	0.8	0.5	–
12.	Laos	–	–	–	–	–	–	–
13.	Rep. of Vietnam	–	–	–	–	–	–	–
14.	Khmer Republic	–	–	–	–	–	–	–
15.	Egypt	–	–	–	–	–	–	–
16.	Iran	1000	1	33	16.5	11	8	–
17.	Turkey	1923	6.25	52	26	17	13	–
18.	Saudi Arabia	–	–	–	–	–	–	–
19.	Kuwait	–	–	–	–	–	–	–
20.	Iraq	–	–	–	–	–	–	–
21.	Jordan	–	–	–	–	–	–	–
22.	Israel	–	–	–	–	–	–	–
23.	Lebanon	–	–	–	–	–	–	–
24.	Syria	–	–	–	–	–	–	–
25.	Rep. of Korea	1187	12.4	37	18.5	12	9	I

Source: U.N. Statistical Yearbook 1973

It can be concluded that for many Asian countries, there are not adequate resources available of their own to produce the minimum per capita energy requirement to sustain a minimum essential quality of life without the massive infusion of energy from outside sources. Even then, the extractable resources available at reasonable costs to satisfy the energy demands seem to be only for a limited number of years.

The position could be analyzed from a different angle. Table IV shows the coal and lignite reserves and annual production of 11 major coal producing countries in the world which altogether possess more than 90% of the world's known reserves. It can be seen from the last column of this table that even if we are to assume that the entire coal production in any particular country is used for its internal consumption only, the percentage contribution of coal to total energy utilization is less than 75%. In many cases, it is less than 40%. The cases where the figures exceed more than 40% can be considered to be those which are exporting coal significantly.

Table V gives details of coal and lignite reserves, present annual production, and years of exhaustion if coal and lignite contributes 25% to 100% of the total energy requirements. It is seen that only India and Japan have any significant deposits available and even their deposits are limited. For example, India's resources will run out in less than 200 years even if it meets only 25% of energy requirements. At present, the coal consumption pattern is somewhat difficult to correlate with the production of coal as many of the coal producing countries export coal to other countries. However, if it is assumed that 50% of the total energy consumption aimed at (i.e. 4 TCE) is contributed by coal, then in India's case the reserves will last less than 100 years.

Table VI gives the per capita production of energy from a possible exhaustion of the coal reserves in 100 years. To this is added the per capita production of energy from a possible exhaustion of the fluid fuel reserves in the same period. The per capita reserves of hydro potential also is given in the table and in the last column, the total per capita available energy per annum. It can be readily seen that only Iran, Saudi Arabia, Kuwait and Iraq exceed the projected minimum energy requirement of 32 MWh per capita per annum. In all the rest of the countries the deficit varies from 16 MWh to very high values. Even assuming there are certain errors in the assumptions and calculations, the wide gap existing between energy demands and availability in the South East Asian countries is very striking. The production in Iran, Iraq, Saudi Arabia and Kuwait for 1972 has been 2976, 3420, 1812 and 852 million MWh[1] respectively which means that these countries would stand to deplete their oil reserves in about 55 years for Iran, 70 years each for Saudi Arabia, Kuwait and Iraq. There is also a great demand now for coal to be exported from coal producing countries to other countries in view of the energy crisis. This will, to a certain extent, reduce coal availability in the coal producing countries.

Table VII gives the present installed capacity per thousand population and the electrical production per capita in the countries under consideration. It essentially shows how little installed capacity the Asian countries have (excepting Japan, Singapore, Kuwait and Israel). Per capita installed capacity varies from a very low .007 to about .14 KW with an average in the range of .04 KW. This can be compared with the installed per capita of 2 KW in USA and 1.4 in UK (1972). Most of the countries have installed capacities less than 2000 MW and many among them especially

[1] Source: *UN Statistical Yearbook – 1973.* Values include natural gasoline, crude petroleum and natural gas.

Table VI
PER CAPITA ENERGY AVAILABLE FROM VARIOUS RESOURCES

EXHAUSTION PERIOD OF 100 YEARS

S.No.	Country	Population (million)	Coal & Lignite: Annual production (10^6 MWh.)	Coal & Lignite: Per capita production (MWh.)	Fluid Fuels: Annual production (10^6 MWh.)	Fluid Fuels: Per capita production (MWh.)	Per capita reserves of hydro power (MWh.)	Total per capita energy available per annum (MWh.)
1.	India	563.5	8552	15.17	15.46	0.03	0.56	15.76
2.	Pakistan	56.1	140	2	58.58	1.04	***	3.53**
3.	Burma	28.9	8.3	0.29	0.92	0.03	–	0.32
4.	Sri Lanka	13.0	–	–	–	–	0.84	0.84
5.	Bangladesh	53.2	–	–	–	–	***	–
6.	Indonesia	121.6	117.6	0.97	192.45	1.58	0.01	2.56
7.	Singapore	2.1	–	–	–	–	–	–
8.	Malaysia	10.9	–	–	23.52	2.15	0.53	2.68
9.	Philippines	39.0	2.2	0.06	–	–	0.38	0.44
10.	Japan	107.0	1584	14.80	1.21	0.01	1.23	16.04
11.	Thailand	36.3	5.87	0.16	–	–		1.16+
12.	Laos	3.1	–	–	–	–	1.0+	1.00+
13.	Rep. of Vietnam	15.3*	–	–	–	–		1.00+
14.	Khmer Republic	5.8*	–	–	–	–		1.00+
15.	Egypt	34.8	–	–	75.17	2.16	0.43	2.59
16.	Iran	30.5	80	2.62	1621.34	53.15	–	55.77
17.	Turkey	37.0	154	4.16	3.35	0.09	1.54	5.79
18.	Saudi Arabia	8.2	–	–	2402.20	292.95	–	292.95
19.	Kuwait	0.9	–	–	1339.18	1487.97	–	1487.97
20.	Iraq	10.1	–	–	591.96	58.60	–	58.60
21.	Jordan	2.5	–	–	–	–	–	–
22.	Israel	3.1	–	–	0.11	0.04	–	0.04
23.	Lebanon	3.0	–	–	–	–	–	–
24.	Syria	6.7	–	–	21.84	3.25	–	3.25
25.	Rep. of Korea	32.4	95	2.93	–	–	0.5	3.43

* Figures are for the year 1963
** Excluding hydro power
*** Figures not available separately for Pakistan and Bangladesh
\+ Based on average figure for hydro power for Thailand, Laos, Rep. of Vietnam and Khmer Republic.

the South East Asian countries have less than 1000 MW and a few less than even 500 MW. In these countries especially the South East Asian countries, such a situation poses problems if they try to introduce large blocks of power from a nuclear station or high capacity thermal station without adequate transmission and distribution systems.

How can this great gap in the Asian scene between needs, existing production and possible production of energy from their own reserves be overcome? Clearly, nuclear energy will have a role to play in the future. Each of the countries will have to decide on their policies and priorities. Japan with a per capita energy availability of only about 16 MWh on a 100 year exhaustion basis of its resources is already consuming about 26 MWh, which means that considerable energy imports are already taking place. It is an example of a country with not enough reserves of energy resources, meeting its energy demands from alternate sources by import. Likewise, each country has to make a cost benefit analysis and develop its own strategies based on financial resources and other factors. Such studies must take into consideration the possibility of tapping the maximum from the 'income' sources of energy.

Since, for obvious reasons, the situation with respect to Japan and Middle East is different, it might be more relevant to analyze the requirements of the rest of the countries in the region. While it is clearly beyond the scope of this paper to discuss in detail all the possibilities, an overall view of the situation can be projected.

Before taking up these countries individually, however, it is of interest to have a look at the uranium resources in the region. India, Japan and Turkey have identified uranium resources with India having the maximum. But even India's reserves of uranium are only minimal. It is quite possible that some of the countries like Malaysia, Indonesia, Burma, Thailand etc. have not been surveyed in detail for their uranium resources. Therefore, the general assessments made now may need correction in the future.

In the middle 60s' the position of uranium resources were considered in detail and the available resources were assessed at prices up to $ 66 per kg. of U_3O_8. Subsequently, assessments were made up to $ 220 per kg. of U_3O_8 and in some cases even up to $ 1100 per kg[2]. These assumptions have been made to indicate that nuclear reactors, being highly capital intensive, the sensitivity of fuel costs even up to high cost of uranium is not critical when compared with power producing plants based on fossil fuels. It has been calculated that in the case of light water reactors the bus bar costs (of electricity) would change only by about 1 mil. per KWh if the price of uranium is increased from $ 22 per kg. to $ 66. The increase would change only by 5 mil. if the price is stretched up to $ 220 per Kg. of U_3O_8. In the case of breeder reactors the price increase of uranium is comparatively little felt in the bus bar costs.

Table VIII gives a rough calculation of the maximum energy available from world's uranium reserves based on 30-100 years of exhaustion of resources. If we take the world as a whole, at a cost of uranium at less than $ 33 per kg. of U_3O_8, per capita energy

[2] Source: *IAEA Bulletin* Vol. 16, No. 1/2, 1974.

Table VII
ENERGY RESERVES, INSTALLED CAPACITY AND ELECTRICAL PRODUCTION

S.No.	Country	Population (million)	Area (sq.km)	Energy reserves Solids & fluids Total (10^6 MWh.)	Energy reserves Solids & fluids per capita (MWh.)	Water power potential Total (10^6 MWh.)	Water power potential Per capita (MWh.)	Installed capacity Thermal+ (MW)	Installed capacity Hydro (MW)	Installed capacity Total (MW)	KW per 1000 population	Electrical production per capita (KWh.)
1.	India	563.5	3280483	856783	1520	320	0.6	11285	6613	17900	31.8	117.8
2.	Pakistan	56.1	803943	19846	354	***	***	1264	586	1850 (1970) P	32.9	132.7
3.	Burma	28.9	678033	922	32	–	–	155	103	258 (1971)	8.9	22.6
4.	Sri Lanka	13.0	65610	–	–	11	0.84	86	195	281	21.6	76.5
5.	Bangladesh	53.2	142776	–	–	***	***	—	—	547 P	10.3	19.3
6.	Indonesia	121.6	1491564	31005	255	0.81	1.01	605	315	920 (1971)	7.6	19.4
7.	Singapore	2.1	581	–	–	–	–	727	—	727 P	346.0	1497
8.	Malaysia	10.9	329749	2352	216	5.36	0.53	728	293	1021 (1971)	93.6	325
9.	Philippines	39.0	300000	220	6	15.10	0.38	1627	549	2176 (1970)	55.8	222
10.	Japan	107.0	372154	158517	1481	131.90	1.23	64562	20734	85296	797.0	4005
11.	Thailand	36.3	514000	587	16			930	475	1405 (1971)	38.7	144
12.	Laos	3.1	236800	–	–	60.0**	1.0	14	33	47 P	15.2	20.6
13.	Rep. of Vietnam	15.3*	173809	–	–			—	—	838 P	54.7	
14.	Khmer Republic	5.8*	181055	–	–			70	—	70 (1971)	12.1	
15.	Egypt	34.8	1001449	7517	216	15	0.43	—	—	4004	115.0	230.7
16.	Iran	30.5	1648000	170134	5578	–	–	2007	800	2807 (1971)	92.0	298
17.	Turkey	37.0	780576	15717	425	57	1.54	1865	877	2742	74.1	303.8
18.	Saudi Arabia	8.2	2149690	240220	29295	–	–	325	—	325 (1971)	39.6	122
19.	Kuwait	0.9	17818	133918	148797	–	–	700	—	700 (1971)	777.8	3661
20.	Iraq	10.1	434924	59196	5861	–	–	840	—	840 (1971)	83.1	223.8
21.	Jordan	2.5	97740	–	–	–	–	50	—	50 (1971)	20.0	99.6
22.	Israel	3.1	20700	11	4	–	–	1470	—	1470 (1971)	474.2	2734
23.	Lebanon	3.0	10400	–	–	–	–	175	246	421 (1971)	140.3	515
24.	Syria	6.7	185408	2184	326	–	–	—	—	354	52.8	182.5
25.	Rep. of Korea	32.4	98484	9492	293	16	0.5	2568	340	2908 (1971)	89.7	391.8

Source: *i) U.N. Statistical Yearbook 1973*
ii) U.N. Statistical Papers Series N J 16 "World Energy Supplies 1968-1971".

*Figures are for 1963 only
**Average figure for Thailand, Laos, Rep. of Vietnam, Khmer Republic
***Separate figures for Pakistan & Bangladesh not available
+Includes nuclear installed capacity also in countries having nuclear power plants

NOTE: 1. Figures are for 1972 except where mentioned otherwise.
2. P indicates power for public use only i.e. does not include power generated by industries for their own consumption.

Table VIII
ENERGY AVAILABLE FROM URANIUM RESERVES

S.No.	Type of reserves	Reserves (10^9 T.C.E.)	Reserves (10^9 MWh.*)	Possible annual generation to exhaust resources in 30 years (10^8 MWh.)	50 years (10^8 MWh.)	100 years (10^8 MWh)	Per capita availability MWh./year for exhaustion in 30 years	50 years	100 years
1.	If used in light water reactors (Recovery cost $ 15/lb U_3O_8)	60-90	163-245	54-82	33-49	16.3-24.5	1.46-2.21	0.89-1.32	0.44-0.66
2.	If used in breeders in the same ore cost range	5000-7500	13600-20400	4530-6800	2720-4080	1360-2040	122.4-183.8	73.5-110.3	36.7-55.1
3.	If used in breeders with ore recovery costs up to $ 100/lb U_3O_8	50000-75000	136000-204000	45300-68000	27200-40800	13600-20400	1224-1838	735-1103	367-551

Source: International Atomic Energy Agency Bulletin Vol. 15, No. 5, 1973

* In terms of electric energy 1 T.C.E. = 2.72 MWh. of nuclear electrical energy.
** Based on world population of 3700 million as in the year 1972.

equivalent in MWh per year for even a 30 year exhaustion will be less than 2.5 MWh. However, there is a quantitative increase if the same is used in breeder reactors.

The above information is only of theoretical interest to many developing countries, most of them not having any uranium and hence are unable to utilize it to the extent they desire. Also, most of these resources would go to feed the power requirements of the advanced countries.

The Indian situation is outlined briefly to give an idea as to how a developing country attempts to solve its vast demands for energy to the extent it can.

As a rule of thumb, it is assumed that 25% of the primary en-

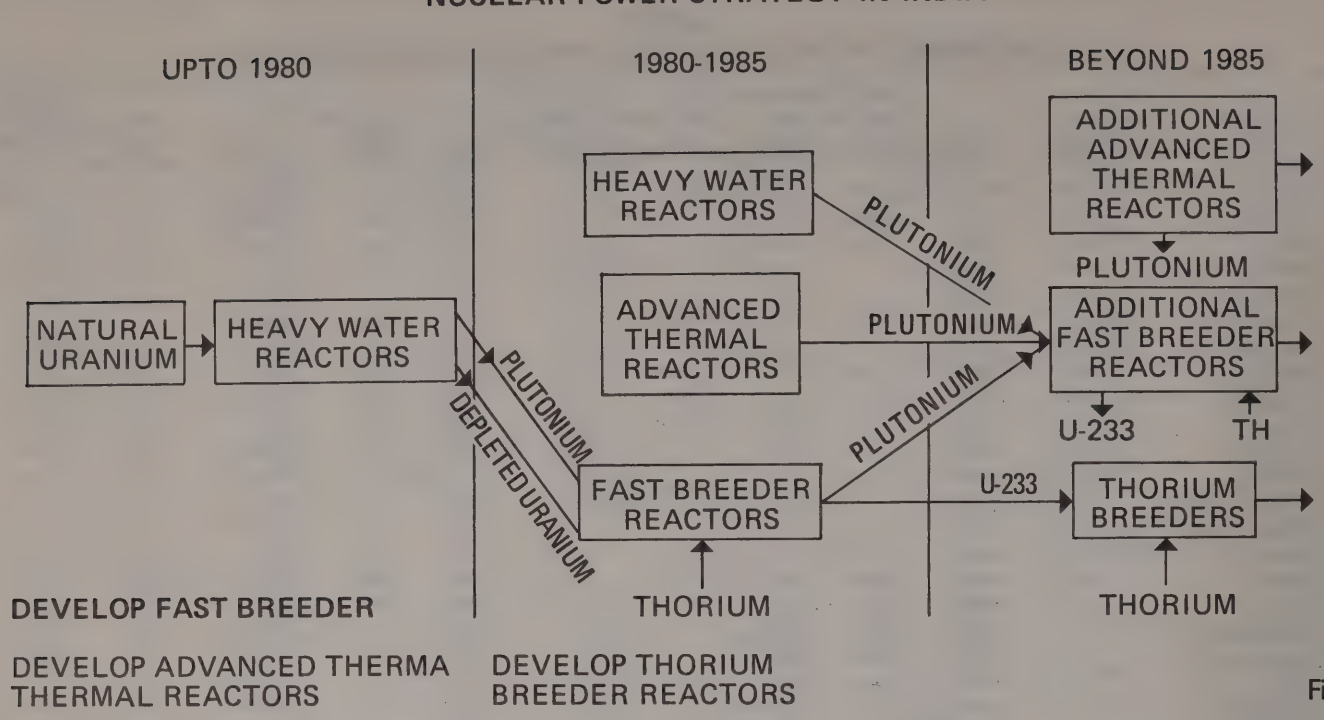


Fig. 1.

ergy is used for domestic and commercial needs, 25% for industry, 25% for transportation and 25% for generation of electricity (gross). Based on a minimum energy demand of 32 MWh per capita per annum, in the context of our discussion, it can be assessed that 8 MWh are required for generation of electricity. This has to be contributed by all sources of electrical production including nuclear energy.

In India, the hydro potential for power generation is estimated at 41000 MW of which 6400 MW were operating in 1970. These sources are located remotely from the industrial areas and many of the rivers are monsoon dependent. Even assuming that the full hydro resources are tapped and used in the most efficient manner, still the maximum power availability from these sources is only about 560 KWh per capita per annum. This figure though higher than the present per capita production from all sources is very much lower than the projected demands. The coal and lignite reserves are assessed at 107 billion tons coal equivalent. It has been shown that the contribution from these sources is only about 15 MWh assuming 100 years as the basis of exhaustion. Of this only 50% is expected to go into electricity power generation; i.e. equivalent of only 7.5 MWh. But this assumes a production of 1000 million tons per annum which is more than 10 times the existing production. A realistic basis would be to assume a maximum coal production tons of about 200 million tons per annum, which means that the contribution to the electrical demand could be about 1.5 MWh thermal only. We have already seen that the power production potential from existing oil reserves is negligible though there are hopes of a much greater contribution from oil in the future. Thus the total maximum possible from all these sources seems to be less than 3 MWh. Even if we assume a 400 million tons annual coal production, it will still not exceed a total figure of 4 MWh from all sources. This leaves a deficit of 4-5 MWh to be filled by other sources of energy for electrical production. Certainly, nuclear energy is destined to play a major role in meeting this deficit. The magnitude of the problem comes to focus when we realize that to make up the 4 MWh per capita deficit (equivalent to about 1.2 MWh per capita actual electrical production) it is necessary to have an installed capacity of about 120000 MWe! This is quite a high capacity to be achieved. To add to this one has to remember that the population increase per annum is about 13-15 million. This highlights how great a problem the developing countries are being faced with in meeting even a tolerably basic energy demand.

Fig. 1 shows the nuclear power strategy in India. The thorium reserves of India are one of the largest in the world. It was realized from the very beginning that India's nuclear power programme will have to be ultimately based on these large reserves of thorium. The uranium available in the country is of low grade and is estimated to be sufficient to support a nuclear power programme of 500 MWe only for the life time of the reactors based on current reactor technology[3]. However, these uranium reserves, though small, are an important factor to trigger our fuel breeding cycle which alone can harness the vast thorium reserves. Taking these aspects into consideration, India's nuclear programme is planned in three phases. At present we are constructing and operating natural uranium-fuelled heavy water moderated and cooled reactors. One reactor is already in operation and five more are at various stages of construction in Rajasthan, Kalpakkam (near Madras City, South India) and Narora (Uttar Pradesh, North India). The natural uranium system was chosen, as in that case we would not need the sophisticated enrichment facilities. In fact the wisdom in India's choice of the heavy water system stands vindicated by developments in other countries.

The Indian nuclear programme envisages that the plutonium from the spent fuel of the thermal neutron reactors will be used to operate fast neutron breeder reactors which while producing power will also convert thorium into fissile U^{233}.

The technological development of fast neutron reactors has not been as fast as one would wish. This has been true the world over. However, it is expected that in about 10 years we shall be successfully operating our first fast breeder system.

In the third and ultimate stage of the nuclear power programme it is proposed to operate breeder reactors based on U^{233} which will convert more thorium into U^{233}.

[3] Source: *Energy, Systems, Development and Policy:* 7th J.N.Tata Lecture by Dr. H.N. Sethna, Chairman, A.E.C. India, March 1974.

It is very important to note that once the fast breeder programme is initiated the growth rate is governed by the plutonium inventory available at the start of the programme no matter how large the thorium resources are. This underscores the importance of our present thermal neutron reactor programme which will help build up a sufficiently large plutonium inventory.

Insofar as the other countries in the region are concerned, there is an urgent need (with the exceptions of the Middle Eastern countries) to explore and exploit new sources of energy. For most of these countries nuclear power may help in meeting their power needs. Conditions vary in each country. To start with, it is most important that a cadre of skilled scientific and technical personnel is created before embarking upon a nuclear programme. Industrial infrastructure has also got to be simultaneously developed. Nuclear technology should not be imported as a "black box" involving continual dependence on outside imported know-how, expertise and equipment. This is neither desirable nor viable from a long-term point of view. Concurrently, while looking for nuclear power development, the search for alternate resources has to be stepped up and existing resources exploited to the optimum. Regional co-operation is important in tapping available resources. For example, the Mekong river has great potential for hydro power. This can be exploited centrally or regionally, but if larger stations are set up the costs of generation and distribution would be lower. The countries of Indochina and Thailand, which in 1971-72 had only an installed capacity of about 2400 MWe with a projected demand of about 7000 MWe by 1985 and 22500 MWe by the year 2000[4], could very well consider the setting up of large capacity power plants and a common transmission system.

Table IX
POWER REQUIREMENTS
OF INDIVIDUAL COUNTRIES (MWe)

	Existing as of end 1968		Planned for implementation for years 1969-73		Additional requirements for years 1974-80	
Country or area	Hyero	Thermal	Hydro	Thermal	Hydro	Thermal
Malaysia*	264	274	Nil	420	252	270
Singapore	Nil	464	Nil	550	Nil	400
Sumatra	1.5	90.5	160	50	**	**
South Thailand*	Nil	70	Nil	60	27	30

* The details are for Western Malaysia and a small portion of Thailand in the south.

** There are preliminary suggestions that the Asahan hydro power project (Sumatra) with an installed capacity of 160 MWe (1974) be expanded by the additional 500 MWe; and a 200 MWe installed capacity thermal power station based on coal or lignite be set up near Palambang in Sumatra after 1974.

A study carried out in 1969 for Indonesia, Malaysia, Singapore and South Thailand shows that regional co-operation can be beneficially employed for power development[5]. Table IX gives the power requirements of the regions considered in the individual countries. It is clear that individually these countries would consider installation of single units of only about 100 MWe each. For unconnected development of the four national grids, nearly 700 MWe of generating capacity will have to be provided between 1974-80. If a single plant is considered, a 500 MWe capacity station (2x250 MWE) may be adequate, due to the economies possible for integrated operation of the four grids. The station whose output would be shared among the participating countries can be located at a site suitable and agreeable to these countries such that the distances for transmission to the countries are minimal. Alternatively, if a dual purpose plant is put up, in addition to power, the water demands for Singapore could also be met. Another possibility is for a central station located in Indonesia (Sumatra) not necessarily based on nuclear power but on fossil fuel. Detailed analysis of such possibilities are required before firm recommendations can be made.

Serious thinking has to be given also by the world community to explore the possibility of increasing the energy output in the countries without apparent substantial natural resources. Vast areas in these countries may still require exploration to find out what the true resource potential is.

Questions are being raised whether nuclear power really is the answer for meeting the short, medium and long-range needs of any country. Since the oil crisis in late 1973, a potential of about 35 billion barrels of oil has been found, according to one estimate[6]. The important point is that this is based on 18 months of exploration only.

Protagonists of nuclear power contend that nuclear energy is cheaper than that produced from oil at current prices and that it is not tied up with oil locales. Uranium being more widely found, is according to them a preferred raw material. Also, for the ultimate development of thermo-nuclear fusion, thermal reactor development is considered necessary.

Against this, there are questions about nuclear risks and waste management, about large inputs of capital, etc. Between now and early 1990's, it is expected that one and a half trillion dollars will be spent if all the present nuclear programmes of the developed countries are to be fulfilled. Nuclear stations are becoming increasingly costlier i.e. up to 5 times compared to those ordered 6 years ago. The cost of uranium has almost tripled during the last two years and though this accounts for a small fraction of the energy cost, the fear is that its availability will be a restrictive factor in the long run.

The fast breeder technology is of course projected as a hope for reducing the cost of electricity produced from nuclear sources. But large-scale commercial application is envisaged for the year 1985 and afterwards. It is not possible to predict what would be the cost of energy then. Developed countries have spent billions of dollars on fast breeder R & D, and still more will be required by the time commercial operations become feasible. Also in terms of safety and long term radioactive waste management, fast breeders have been under critical scrutiny.

The major hope lies in the development of thermo-nuclear fusion as early as possible, because of its immense potential and safety. The commercial exploitation of fusion seems possible only by the year 2000. If a strategy can be developed so that humanity's future needs for energy in both developed and developing nations can be met by fusion and other important sources, such as solar energy, then, there is some hope for the large under-privileged population living in the Asian region.

The complexity of the problem make any treatment inadequate. But the purpose of the paper would have been served if it helps to expose the magnitude of the energy and power needs of a region which accounts for a large percentage of the world's population.

[4] Source: Committee for the Coordination of Investigations of the Lower Mekong Basin, Third Engineering Seminar, Vientiane, Iaos, Nov. 69.

[5] Thomas, K.T., *Preliminary Study on the Feasibility of Regional Power Development including Desalination of Sea Water* – Report submitted as a special consultant to UN-ECAFE, Bangkok, February 1969.

[6] Source: *The Economist*, Volume 255, No. 6872, May 10, 1975.

ENERGY OPTIONS FOR DEVELOPING COUNTRIES IN AFRICA

Shem Arungu-Olende

INTRODUCTION

The development and use of energy is an integral part of the development process in any economy, whether it is an industrialized country or a developing country. Energy resource availability, supply and efficient use are therefore questions of particular importance to any country, subregion or region.

Energy consumption of the African countries has been growing steadily in the past years and a similar trend may obtain in the future. In most of these countries, non-commercial forms of energy, such as wood and wood products (e.g. charcoal), straw, baggase, animal waste still constitute the major source of energy, particularly in the rural areas. Of the commercial energy resources including coal, petroleum, natural gas and electricity, petroleum claims the largest share of total consumption (67.09 percent for the developing countries of Africa in 1972)[1]. It is, however, uncertain whether petroleum will continue to play the dominant role in the future in light of the recent sharp increase in its price.

To meet the expected increase in demand for energy, African countries will have to give serious thought to and adopt a number of options, both medium-term and long-term, that will best supply their respective requirements and that are best suited to their respective conditions. This is not going to be an easy task. Most of the African countries have as yet not undertaken a detailed inventory of their indigenous resources.

The need for an inventory and development of indigenous resources has been rendered the more urgent as a result of the above mentioned increase in the price of crude petroleum products, together with the general upward shift in the price of imported energy resources.

The rate of growth of installed generating plants in developing Africa has been of the same order of magnitude as that of total (commercial) energy in the 1961-1972 period. It is expected that the same general trend will obtain in the foreseeable future. Nearly fifty percent of this installed capacity is oil-fired; the recent increase in the price of crude petroleum products will, therefore, influence future electrical capacity growth in Africa, especially in respect of oil-fired thermo-plants.

In most of the African countries generating plants are, in general, still grossly underutilized, partly because (at least for some countries) generating plants are still isolated from one another and more substantially because of inherent problems in forward planning.

Although over 70% of Africa's total population lives in rural areas, the supply of energy in these areas is inadequate by any standards. Any appraisal of Africa's energy supply options must give serious attention to the energy requirements of these areas. The widespread use of wood and wood products in these areas results in deforestation, with adverse consequences on the soil, water table and general climatic characteristics of the affected areas.

COMMERCIAL ENERGY CONSUMPTION[2]

The combined consumption of commercial energy in the whole of Africa amounted to 134 mtce (million tons of coal equivalent), which represented only 20.4 percent consumption of the developing countries for the same year, but which nearly doubled the 70 mtce consumed in Africa in 1961.

There were considerable differences and disparities between the levels of energy consumption and rates of growth in the developing countries of Africa, on the one hand, and South Africa, on the other. For example, South Africa alone consumed 44 mtce and 65.33 mtce in 1961 and 1972 respectively, accounting for about half of the total consumption of Africa in each case. The average annual growth rate for the developing countries of Africa for the period 1961-1972 was 10.25 percent, a figure much higher than 3.65 percent for South Africa for the same period. There were also differences in the levels of energy consumption as well as growth rate between the developing countries of Africa.

Combined electrical energy consumption for Africa in 1972 was about 102.047 million KWh of which 59.081 million KWh was consumed in South Africa and only 42.966 million KWh in the developing countries of Africa. Electricity consumption rate of growth has lagged that of total energy in the 1961-72 period (8.7 percent per annum as compared to 10.25 percent per annum)[3].

While commercial energy consumption in developing Africa has followed the general average for all the developing countries, when viewed in a world perspective, developing Africa's share of world energy consumption has been a meagre 0.86 percent in 1961 declining to 0.58 percent in 1972.

ENERGY RESOURCES AND RESERVES

This section briefly discusses Africa's resources, reserves and production trends, where information is available.

Hydropower

While Africa has vast hydroelectric energy resources only a small fraction of this has been exploited to date. Its hydropower potential is of the order of 145,000 MW, which represents 26.16 percent of the world's total potential (of 555,000 MW). The sites are, however, not evenly distributed, with 56 percent located in Zaire, 8 percent in Madagascar and one percent in Zambia. The three countries alone thus claim as high as 65 percent of Africa's hydroelectric energy potential.

The installed hydropower capacity in Africa in 1972 was 7647 MW or 29 percent of the whole continent's installed electric power (hydro and thermal). This amounted to only 5.3 percent of the continent's hydropower potential. Great opportunities for the continent thus lie in the exploitation of the vast hydroelectric generating potential.

The continent produced, in 1972, 30.024 million MWh of hydroelectricity (a mere 2.16 percent of world production), which

[1] World Energy Supplies (ST/STAT/SER.J/17).

[2] *The Role of Energy in the Development of Human Settlements in Africa,* by Economic Commission for Africa (E/CN.14/HUS/6), presented at Regional Conference on Human Settlements, Cairo, June 21-26, 1975.

[3] *ibid.*

represented a contribution of 29.4 percent of the total of Africa's electricity consumption for that year.

The development of hydroelectric energy resources in Africa has been impeded by the comparatively large size of some of the sites and the heavy initial capital investment required by way of dams and generating facilities in relation to the size of the local markets. It is, however, hoped that in the future, with the electricity demand in Africa continuing at current levels, with petroleum (and petroleum products) prices soaring and with the expected sub-regional and regional cooperation in the development of hydroelectric energy resources, the pace of hydroelectric development and exploration in Africa will increase.

Large scale hydroelectric installations can be economically justified only where the site provides large hydraulic heat and larger flow rates. In addition to the larger waterfalls, there are a larger number of smaller ones in many countries in Africa. The development of small scale machinery that can economically be harnessed to supply local needs requires serious attention. Work has been carried out on the development of special types of hydrosystems that could be used for such purposes[4]. Further research and development work has been carried out by EDF (Electricité de France) which has reported encouraging advances in the field[5].

Hydrocarbons

(a) PETROLEUM

Significant petroleum development in Africa has taken place in the past two decades, exemplified by the discovery of large oil and gas fields in Algeria and Libya. The past few years have, however, witnessed decreased exploration activities resulting in a lower rate of discovery of crude petroleum than in the previous years. For example, during the last three years, only 9.4 billion barrels of proved oil reserves were discovered in Africa as compared to 40 billion barrels discovered during the 1960's[6].

Substantial oil and gas reserves are to be found in Algeria, Angola, Congo, Egypt, Gabon, Libya, Nigeria and Tunisia. Fairly good discoveries have also been made in Cameroon, Dahomey, Ghana, Senegal and Zaire, particularly offshore. In addition, recent exploratory results indicate that there are good prospects for discoveries in the coastal basins of Eastern Africa and Southern Africa. There are also good prospects of further oil discoveries in the basins with existing proved reserves such as the North African Atlas area, covering Tunisia, the North African Platform, stretching from Morocco to Egypt, and the Gulf of Suez and Red Sea basins.

As a result of the increase in the price of crude petroleum and products, it is expected that new areas in Africa will come under exploration. Increased exploration activity is in fact, already underway in many locations in the continent, either offshore or in the interior.

Africa's proved petroleum reserves are estimated at some 68.3 billion barrels which is 9.5 percent of the total world proved reserves (715.7 billion barrels)[7].

(b) NATURAL GAS

There are natural gas occurrences in Algeria, Congo, Egypt, Gabon, Libya, Morocco, Nigeria, Rwanda and Tunisia. Proved reserves of natural gas in Africa are estimated at 31,974 billion cubic feet, which represents some 12.3% of the world's proven reserves (of 2,555,064 billion cubic feet).

The discovery rate of natural gas has been much better than for crude petroleum during the last three years; about 122,000 billion cubic feet of proved natural gas reserves were discovered. The utilization of natural gas has, however, not caught on in Africa. Consequently up to 90 percent of produced natural gas is burned in the atmosphere.

The continent's crude petroleum production was in the 1950's about 100,000 barrels a day, with Egypt as the largest producer. In the early 1960's with Algeria and Libya joining the ranks, the continent's production passed the one million per day mark and continued to rise in the second half of the decade. By 1970 Africa's production averaged about six million barrels per day. In 1974, Africa's crude oil production was estimated at about 2 billion barrels, representing approximately 10.5 percent of the world's production for the same year. Nigeria became a producer towards the end of the 1960's and is today the single largest producer in the continent.

Although Africa as a whole is a net exporter of energy, the great majority of developing countries of Africa have remained net importers of commercial energy, principally petroleum. The burden and pressure on the balance of trade and balance of payments caused by the sharp increase in the price of petroleum and petroleum products has been excessive for many of these countries, and has in many cases resulted in unprecedented slackening of economic activity boardering on recession, in turn causing an aggravation of often acute unemployment problems.

Coal

Estimated reserves of coal in Africa are of the order of 16 billion metric tons (2.7 percent of world reserves of 590 billion metric tons) most of which is located in South Africa. It is extremely difficult to estimate the extent of coal resources in the developing countries of Africa, since exploration in these countries is far from complete. Significant reserves are also to be found in Algeria, Botswana, Morocco, Mozambique, Nigeria, Rhodesia, Zambia and Zaire, and to a smaller extent, Egypt, Madagascar and Tanzania.

One point is clear in relation to coal resources and reserves in Africa, and, for that matter, in any other part of the world: with the recent increase in the price of crude petroleum (and petroleum products) many hitherto marginal or sub-marginal coal deposits have now become viable in economic terms. This will definitely have a marked effect on the estimate of recoverable coal reserves.

In 1973 Africa produced 67.8 million metric tons of coal, equivalent to 3.9 percent of the total world production of 1.7 billion tons. Of the 67.8 million tons, 92 percent (62.4 million tons) and 4.4 percent (3 million tons) were produced in South Africa and Rhodesia respectively, the two countries together thus accounting for 96.4 percent of Africa's total coal production.

Oil Shale

Oil shale is a sedimentary, laminated rock containing kerogen, which contain up to 40% by weight of oil. Oil shale deposits

[4] A.L. Johnson, *Non-Conventional Sources of Energy for Developing Countries,* Document prepared for the United Nations Committee on the Application of Science and Technology to Development (EAC.52/XX/CRP.7/ANNEX).

[5] Xavier Ract-Madoux, *Small Hydroelectric Plants Equipped with Encapsulated Generator Sets,* Paper submitted for the Interregional Seminar on Rural Electrification, New Delhi, December 2-12, 1971 (ESA/RT/Meeting IV/8).

[6] Economic Commission for Africa *Status of Energy Resources in Africa,* Draft Internal Report, May 1975.

[7] *ibid.*

have been reported in Madagascar (estimated reserves of oil: 4 million tons), South Africa (19 million tons of oil) and Zaire (15 billion tons of oil). Unestimated reserves are also to be found in Egypt, Gabon, Mali, Morocco, Niger, Somalia and Uganda.

It has hitherto been uneconomic to extract oil from shales in the face of low prices of conventional energy sources coupled with technical problems. These have combined to keep its development at low pace. The situation has changed drastically over the past 18 months, as a result of large increases in the price of crude petroleum and petroleum products. It is hoped that many African countries will give serious attention to the exploration and development of their national oil shale resources.

Tar Sands

These are sands impregnated with heavy oil that is too viscous to permit recovery by natural flowage into wells. In Africa tar sands are known to occur in Ghana, Ivory Coast, Madagascar and Nigeria.

The first large scale mining and extraction operation of tar sand deposits was in 1966 in Athabasca, Alberta, Canada[8]. With improvements in tar sand extraction technology now underway and with the high level of current prices for petroleum, it is apparent that the production of oil from tar sands has reached the point of economic viability. It is, therefore, likely that African countries having tar sand deposits will evaluate or reevaluate their tar sand deposits with a view to commercial utilization of the deposits.

Geothermal Energy

Geothermal energy resources are derived from the hot internal core of the earth. Natural manifestations include volcanoes, geysers, fumeroles, hot springs etc., while the sources harnessed by humanity include stream wells and hot water wells.

Successful geothermal production of electricity has been at Larderello (Italy), Wairakei (New Zealand) and the Geysers (USA), while the use of geothermal hot water is widespread in New Zealand and Iceland. In Africa geothermal exploration is underway in the Rift Valley in Kenya, Ethiopia and the territories of Afars and Usas (near Djibouti). Geothermal manifestations have also been observed in Uganda, Tanzania and Zaire. There is also a geothermal potential in Chad, Malawi and Somalia. Zaire has a plant, utilizing geothermal energy, in which low-pressure steam is used to drive a 220 KW generator set for mining purposes.

Although not widely distributed throughout the continent, geothermal resources are expected to provide a substantial portion of the energy requirements, at least in the countries that are endowed with this source.

The use of geothermal energy to produce electricity offers a number of attractive features; in comparison with the fossil-fuel fired plants, the requirement of a boiler is eliminated, thereby reducing both capital and maintenance cost for the equipment, and since no fuel is involved, pollution problems relating to combustion and fuel residues are eliminated.

On the other hand, geothermal fluids are, in general, corrosive and abrasive and thus require the use of special materials for handling. There may also be need for preventive maintenance procedures in the operation of the pipeline and power plant. All this can add appreciably to capital and operating costs. Furthermore, steam or hot water from a geothermal well cannot be conveniently stored as can, say, petroleum, nor is it easy to shut down a geothermal well. It is, however, possible to alleviate these problems through careful design and operating procedures.

Solar Energy

The whole of Africa possesses this form of energy in abundance and an increasing interest is now being shown in its development. The number of African states involved in solar energy research or development is increasing, though the activities undertaken so far are still in the experimental stage.

A solar energy research and development centre has been in operation for some time now at Niamey, Niger – the office is active in theoretical and experimental studies on concentrators, water pumps, and on the development and manufacturing of water bearers as well as in socio-economic studies in the application of solar energy in developing countries. In other African countries such as Chad, Mali, Senegal and Upper Volta work is at different stages on the design, improvement, installation and operation of solar collectors and pumps.

Solar thermal energy has been in use as a heat source from time immemorial, for drying crops and building materials, for baking and for food preparation by dehydration. The more recent, technologically advanced operations include solar heaters, solar stills, solar powered machinery and refrigeration devices; solar furnaces represent the farthest advance in the thermal utilization of solar energy, although the use of these had tended to be restricted to producing high temperatures for laboratory and experimental purposes.

Technical and economic factors have thus far limited widespread use of solar devices despite its advantages: inexhaustibility, enormous rate of supply to the earth's surface, universal distribution, neglegible cost (as raw material before conversion), and apparent freedom from environmental damage.

These technical and economic factors stem largely from the fact that solar energy is variable (geographic, seasonal, day-night and atmospheric interference) as well as of low intensity compared to that obtainable from such sources as fossil fuel etc. There is an urgent need for further research effort into the ways of overcoming the technical and economic hurdles in order to open the way for widespread practical utilization of solar energy, especially with regard to solar heating and cooling devices, solar pumps and devices for electricity generation.

In Africa, as in developing countries in general, there is need for the development of appropriate solar devices that are in harmony with both the cultural and physical characteristics of the rural (and sometimes urban) part of the country, based on the concept of user standards. In developing such devices it must be realized that once the appetite for energy has been aroused in these areas, demand tends to increase at a steady rate; the devices must therefore be based on concepts that the intended user understands and can expand as the need arises.

Biomass[9]

Photosynthesis converts electromagnetic energy into chemical energy. Plant life is based on this process, wherein, carbon dioxide and water are converted to carbohydrates and oxygen by utilizing electromagnetic energy absorbed in the pigments of the green cells of the plants. The chemical energy stored in the carbohydrates can be utilized to form more complex organic compounds by enzymic processes energized by the oxidation of a portion of the plant cell carbohydrates.

8 "World Energy Reserves, Supply and Demand" in *Projections of Natural Resources Reserves, Supply and Future Demand,* Document submitted to the Committee on Natural Resource, Third Session, New Delhi, India, February 1973 (E/C 7/40/Add.1).

9 *ibid.*

To date emphasis has been on photochemically produced energy only for food and cellulose production; this has led to the neglect of the important potential of plant life as a primary source of energy. In order to check this trend, it may be necessary to grow plants specifically for their fuel value. Algea would fit well into this latter category as they are among the most efficient in the photosynthesis conversion process; however, they require special resources for cultivation.

One of the most efficient of the higher plants, readily cultivated by common methods in many developing countries in Africa, is sugar cane, the juice of which can be extracted and fermented to produce alcohol; by itself or mixed with gasolene, alcohol could run internal combustion engines; even agricultural pumpsets could be run on alcohol, with only slight modifications to their engines. In the African countries with excess capacity of sugar cane production, its use as a potential energy source needs to be given serious consideration.

Nations with inadequate agricultural capacity or those which have difficulty in producing sufficient food can produce fuel from organic wastes through anaerobic decomposition. In anaerobic decomposition specific bacteria decompose carbohydrates to methane and carbon dioxide while releasing small quantities of heat. The residual organic sludge and carrier water retain the same organic nutrient and fertilizer as those resulting from aerobic decomposition.

Thus if the organic wastes can be gathered and introduced into anaerobic digesters without excessive energy expenditure a useful energy results. The resulting methane can be used to produce thermal energy for heating, cooking or powering heat engines; or it can be stored as preserved gas. It can also be catalytically converted to methyl alcohol, which is then readily stored as a liquid, to be used either immediately or at some later date.

In the energy-poor, food-poor regions of Africa, it may be necessary to practice the composing of organic wastes in order to produce fertilizers to aid food production. In the recent past artificial fertilizers, produced from hydrocarbons, particularly natural gas, of which African countries have a poor supply, have been at such low cost that compost fertilizers appeared uneconomic. With the current high energy prices, the situation may very well have changed in favour of composting. In reference to composting practices, anaerobic procedures should be introduced and encour aged, since not only is the nutrient value of the waste retained, but methane is also produced.

Anaerobic digestion for biogas and fertilizers production is already extensively practiced in certain areas of the developing world[10]. It is hoped that the methods will find widespread introduction in Africa, where rural areas would no doubt reap huge benefits from both fertilizers and methane.

Wind Energy

Wind energy, like solar energy, has been used by man from the dawn of history. Its use has been limited in comparison to other forms of energy due to its fitful availability, impossibility of transportation over long distances and inequality of distribution. Furthermore, because of the low density of the air in some areas, small capacity wind mills are bulky compared with other prime movers. In addition, the variability of wind speeds is not conducive to the desirable constance of voltage and frequency.

The problem of matching load to random availability of windpower can be partially solved, especially in less isolated areas, by a parallel operation with a thermal (or hydroelectric) plant, which can then pick up or shed load so as to adjust to the difference between bad demand and the contribution from wind-power.

For isolated plants, the problem of load matching may be reduced by the introduction of some means of energy storage. One such scheme that offers promise is to use the variable power output wind to decompose water into hydrogen and oxygen both of which would be stored under pressure and recombined in a fuel cell to generate electricity on a steady basis. Further research effort is required to establish the best possible conditions for the proper functioning of such a system.

There are opportunities for utilizing energy in Africa, especially in the coastal areas where regular winds prevail.

Nuclear Energy

Insufficient exploration has been undertaken in Africa to allow for a good estimate of the uranium potential in the continent. However, a recent estimate by IAEA gives 390,000 short tons of reserves of U_3O_8 at a price lower than US10/lb (40% of the world's reserve of one million tons at the price range) and some 94,000 short tons at the price range between US 10/lb and US 15/lb U_3O_8 (12% of the world's reserve of 750,000 short tons at the price range[11].

In the developing countries a number of factors have precluded the widespread use of nuclear energy for electricity production. First, there is the technical problem of the limit on the generating plant in so far as it conflicts with the economics of scale.

The choice of maximum acceptable unit size is based on the permissible disturbance to a system which can be tolerated on the sudden loss of the unit, the disturbance being measured in terms of frequency deviation and whether or not automatic load shedding devices operate. In general the limit on the unit size is, on the average, of the order of 10% to 15% of the installed capacity or peak load.

This then limits the number of countries in Africa that can introduce nuclear generating units into their power system in the foreseeable future. In the IAEA Market Survey for Nuclear Power in Developing Countries (1973) it is reported that manufacturers indicated no interest in plant sizes below 400 MW-600 MW as this would be uneconomic. Taking into account the 10% to 15% limit referred to above this would require a system with an installed capacity into the range of 2667 MW to 6000 MW; few countries in Africa have power system installed capacity in this range for the foreseeable future.

The second factor hindering widespread nuclear energy use for electricity production is that few developing countries can afford to raise enough capital to cover the very high initial capital cost of nuclear power plants. The development of energy resources is capital intensive. Many of the developing countries do not possess adequate financial resources to meet the requirements for energy development and will, therefore, have to borrow from international markets or organization, or on a bilateral basis. It must be emphasized that these countries will be borrowing for not only energy resources but also other, even more pressing devel-

[10] R.D. Laura et al, "Increased Production of Biogas from Cow Dung by Adding Other Agricultural Waste Materials", *Journal of the Science of Food and Agriculture*, Vol. 22 (April 1971); and
R.B. Singh, "Building a Biogas Plant", *Compost Science*, Vol. 13 No. 2 (1972).

[11] *ibid.*

opment requirements; so that, in effect energy may not receive enough funds for the development of the sector, and whatever goes to the sector will have to also meet the requirements other than electricity development in which nuclear energy may be part. Nuclear energy would therefore consume whatever little finds its way for electricity development.

Thirdly, in considering the introduction of nuclear plants in the developing countries of Africa, very serious thought must be given to the training of operating, maintenance and supervising personnel, and in the longer run, of the management and running of the plant installations. Lack of skilled personnel in these countries has been one of the bottlenecks for proper energy development even with respect to conventional sources of energy such as fossil-fuel fired plants.

The above misgivings apart, nuclear energy has promise in Africa in the longer run i.e. there is ample scope for the introduction of nuclear plants into a number of African countries' power systems. For one thing, the recent price increase in petroleum and petroleum products has dealt many of the African countries a stunning blow that has further aggravated their already adverse economic situation.

Moreover, in a sufficiently large number of African countries, the systems installed capacity shall have grown to large enough levels to take full advantage of economies of scale of the nuclear plants. Furthermore, it is expected that with the industrial and economic development of these countries, the high initial costs of the nuclear plants will be within the reach of some, which should have the capacity to train personnel for the operation and maintenance, supervision and eventual management of the installations and which should have the organizational capabilities required in the proper running of nuclear programmes. It is also hoped that advances in nuclear technology together with a concerted effort in the development of smaller scale units will bring nuclear plants within the reach of many developing African countries.

Some General Remarks

Although the price of crude petroleum and petroleum products rocketed some 18 months ago, there are so far no indications that the supply of petroleum and products of petroleum-deficit African countries will be threatened through shortages. There are in fact good prospects for further discoveries in the existing as well as new areas which together should be able to put more of this commodity at the disposal of the African countries.

It is, however, in the interest of individual African countries to undertake systematic survey and inventory of their energy resources in order to enable them to plan the most suitable resource development strategy for their needs. In this context special emphasis should be placed on the need for the formulation of effective energy policy at the national, subregional or regional levels; the policies should have clearly defined objectives and should be able to reflect the unique needs of each country, and at the same time be consistent with the regional and subregional set up.

It is also in the interest of individual African countries to formulate guidelines for, and implement, energy conservation. This could result in substantial savings in energy use for countries that are already hard pressed financially. Better conservation would thus stave off the currently observed gross under-utilization of electric generating plants in African countries (in the region of 3167 KWh/KW on the average for 1972) through better planning and maintenance procedures.

There is also a strong case for cooperation among African states in the search for new deposits of petroleum and natural gas; in the development, on a subregional basis, of hydro, coal, oil shale, tar sands and geothermal energy resources and in adopting measures (with oil producing countries) that would guarantee the supply of crude petroleum and products to them, under mutually acceptable conditions.

ENERGY OPTIONS FOR LATIN AMERICA

JORGE SABATO

I am not going to speak about energy options as in an energy conference, but about the rationality of introducing nuclear power to Latin America. Moreover, aside from the energy aspect there are and have been other reasons behind the decision taken by several countries in Latin America to go nuclear.

The Latin American countries can be grouped in three categories – in respect to their attitudes to and problems in developing nuclear energy. The first group consists of Argentina, Brazil and Mexico – in alphabetical order. The second group consists of Cuba, and some of the Caribbean islands, for geographical reasons, and the third group are countries of the so-called Andean Pact – Venezuela, Colombia, Ecuador, Peru, Bolivia and Chile, put together for institutional reasons. They are organized in a kind of Common Market in industry, commerce and many other things.

The countries of the first two groups – Argentina, Brazil and Mexico, and Cuba and the Caribbeans – are already engaged in nuclear development, while the countries of the third group – the Andean countries – are not yet engaged, and it does not seem as if they are going to be engaged by the middle of the 80's.

Let me start with a short description of the situation the countries of the first group – Argentina, Brazil and Mexico – find themselves in.

The situation in **Argentina** is as follows: at the present time one nuclear power station is operating producing 380 MWe per year. It is a natural uranium heavy water reactor, but not a Canadian type. Another nuclear power-station is under construction, a CANDU type of 600 MWe; the construction of a third and fourth station for 600 Megawatt has already been decided on, and they are in the first stage of planning.

By 1990 Argentina must have in operation 10,000 Megawatt nuclear power, and by the year 2,000 the amount of nuclear power must be about 30 to 35,000 Megawatt. Why this rapid development in Argentina? From the point of view of energy supply, it is very clear. Argentina has little coal – the amount is only 1/2 million tons per year, which offers no solution to our energy problem. Argentina is not self-sufficient in oil (only about 90%), and the oil resources of the country are very limited and too small to supply the amount of energy needed in the next decade.

Hydro-electricity was insignificant in the past, but is now about 12% of the total power of the country. But once you estimate the amount of energy needed in Argentina in the next 25 years, you realize that the hydro-electric power if 100% used will only satisfy 25% of the future needs by 1990. The situation of coal is not going to improve very much, and the situation of oil is going to be more or less the same, if not going down. Thus in 1967 the decision was taken to go nuclear; there was no other energy option available considering the needs of Argentina.

In **Brazil** the situation is the following: There is one nuclear power station being constructed in Brazil now. This is a Westinghouse-type reactor of about 600 Megawatt using enriched uranium. A second nuclear power station with two or perhaps three reactors has already been decided and is going to be built in the same place. By 1990 the needs of Brazil seem to be in the order of 15,000 Megawatt nuclear. This again results from an analysis of coal, oil and iron supplies of the country. Brazil has a very powerful programme in hydro, in fact the biggest hydro-electric power station in the world is going to be built at the Paraña River between Brazil and Paraguay.

Many other hydro-electric resources are being explored and developed in Brazil. The country has some coal which is used for iron and steel production and for electricity. The oil situation in Brazil is worse than in Argentina, and a high percentage of the oil consumed in Brazil is imported. This of course is one of the reasons why the nuclear programme gathered such a tremendous momentum in the last year. The oil crisis had a significant impact on Brazil's balance of payment, and as a consequence the Brazilian government took the decision a few months ago to go nuclear at an extraordinary pace. Just at this moment it is about to sign a contract for eight nuclear power stations using enriched uranium, to be installed in the next decade. The problem is going to be to install a facility for enriching uranium in Brazil. This is a rational consequence once you have such a big nuclear development programme.

Mexico has a situation intermediate between Argentina and Brazil. The existing oil resources are larger than in Brazil assuring an oil supply as good as in Argentina. The situation of coal is worse than in Brazil. Mexico has a nuclear power station under construction – a boiling water type, enriched uranium, 550 Megawatt. The decision for another unit is being taken these days, and it seems that by the year 1990 Mexico will have a 10,000 Megawatt nuclear and by the year 2000 the total nuclear power will be 50,000 Megawatt. Thus you see that by the year 2000 Brazil will have the highest installation of nuclear power, followed by Mexico, and then Argentina. In these three Latin American countries together, there will be nuclear power of the order of 150,000 Megawatt by the year 2000.

In the second group there are two countries, **Cuba** and **Jamaica** which, for geographical reasons, are in a similar situation: isolation and lack of natural resources for electricity – there is not enough hydro, no coal, no oil. For that reason a nuclear power station would be one of the best solutions for Jamaica. The decision has not yet been taken, but according to my information it is forthcoming. Cuba has already taken the decision about two months ago to have a Soviet pressurized water type nuclear power station by 1979/80 of about 440 MWe. The complete dependence of Cuba on oil from foreign sources had originally led already in the late 50's to a decision to go nuclear.

In the third group the situation is the following: **Colombia** is very rich in coal, and the existing supplies are adequate for the next few years. It is not very rich in oil but it has enough for the time being. **Venezuela** is one of the biggest exporters of oil, so there are no immediate problems. But there is the awareness in Venezuela that oil alone will not solve all the economic problems

* This is a shortened and edited version of the recording of Dr. Sabato's presentation to the Hearing Group.

of the future. life. It is better to take some actions on production in time and to protect the available natural resources.

Venezuela is therefore analyzing its possibilities. The same is happening in **Ecuador** where a lot of oil has been found, and in **Peru. Bolivia** and particularly **Chile** are open questions. Chile has a lot of hydro-electric energy and practically all of it is already under utilization.

Let me add something about the other reasons which are behind the decisions of some of these countries to go nuclear. One of the very important driving forces which had led up to these decisions were questions like this: what had happened to oil and electric power production in our countries? The past experience was that oil and electricity were resources that were exploited by others. The sentiment today is that history is not going to be repeated. In respect to nuclear energy this means that we are not prepared any more to just wait and see what the powerful nations are going to do, to stand still until they decide to come to our country. One can imagine that at the beginning of the worldwide development of nuclear energy it was important to know whether there was uranium on one's territory before somebody was coming to look for this increasingly important natural energy resource.

Furthermore I would say that in the case of nuclear energy, it was a field that really inspired the idea of self-reliance in the technological sector that is now spreading all over the world. This idea involves some kind of capability to take your own technological decisions in this field. Of course you can commit many mistakes by taking your decisions in that way. But at least you are the owner of your mistakes and not suffering the mistakes of somebody else.

There was also the problem of nuclear weapons of course. This problem has never come into the picture very clearly because the countries which have nuclear weapons do not talk about them, they just build them, they experiment, and the other countries keep discussing them.

It is well known that two countries in Latin America did not sign the Non-Proliferation Treaty, namely Argentina and Brazil. Of course many people are very unhappy about this: we have not behaved well in the world community. In the case of Argentina, I know the rationality. For Argentina one attitude in foreign policy is not to discriminate against any other country. Concerning the Non-Proliferation Treaty, the position of Argentina is quite clearly presented to the United Nations. The treaty discriminates between those who have and those who do not have nuclear weapons. Those who already have nuclear weapons are free to keep developing them without any restriction but the others are prevented from getting them, and this is completely unfair from the point of view of energy politics.

It is not that we in Latin America are doing anything yet to produce weapons, it is just that we also wish to have our own capacity to judge, our own technical autonomous capability to decide what is best for our countries in that matter. For that reason we try to learn and develop as much as possible.

There is finally a third point that is having a bigger impact every day in Latin America. It is the fact that nuclear energy was introduced in our countries, at least in Argentina first and then in Brazil, according to a different pattern than it had been the case with electricity or oil technology. In the latter two cases the technologies were introduced about 50-60 years ago by buying a "black box". Nuclear energy follows a different approach, what we may call a "grey box". It is not a "white box", but it is not a "black box" either that you buy just blindly. Now you ask the proprietor to open the box and to understand what is inside the box. You try to learn and you try hard to develop your own local capability. This procedure was followed very much by the Indian-Canadian experience and we have been following a similar pattern in Latin America.

The fact that the first nuclear power station in Argentina, the first nuclear power station in Latin America, was not a "black", but a "grey" box has also tremendous consequences in other sectors of industry and of public works. Our countries are not accepting any more the importation of technology as it was in the past in the petro-chemical industry, in iron and steel manufacturing, in gas industry, and in many other activities.

NUCLEAR POWER – COMPATIBLE WITH PEACE?

The Relation between Nuclear Energy and Nuclear Weapons

JAN PRAWITZ

An important issue in the current nuclear power debate is the fact that the plutonium produced together with energy in most nuclear reactors, might also be suitable as the explosive substance in atomic bombs. An extensive installation of nuclear power stations would over a long period of time result in the build-up of considerable stockpiles of surplus plutonium and thus produce the fundamental prerequisites for atomic bomb-making in a large number of countries of the world. In the view of many, such plutonium would sooner or later be used for bomb-making and subsequently for nuclear aggression. The necessity of prohibiting this possibility would, according to this view, greatly strengthen the conclusion that nuclear power must be stopped in all countries, thus removing the very basis for bomb-making.

If peace and nuclear power are incompatible, it is reasonable to assume that everybody will be for peace. But is that the pertinent problem? Is it possible to handle plutonium in such a way as to have both nuclear power and a peaceful world?

As the organization of the international society is primarily based on sovereign states, the analysis of the plutonium problem is better divided into two parts. One is the possible proliferation of nuclear weapons among national states. The other is the possibility that terrorists or sub-national groups might get access to fissile material and make their own nuclear explosive devices. It is also necessary to extend the problem to include the protection of highly enriched uranium-235, in addition to plutonium.

Technological background

When plutonium is produced along with power in nuclear reactors, it is fixed to highly radioactive fuel elements, fatally dangerous to handle except in special facilities. Before separation from the spent fuel, plutonium would thus watch itself. If after a cooling period used fuel is processed, plutonium may be produced in chemically pure form and could either be recycled as fuel in reactors or stockpiled. Only part of the plutonium produced in the future would thus be available in stockpiles. How big these stocks will grow will depend on a number of factors, but their content could very well reach a considerable size in the 1980's.

This plutonium would be reactor-grade, i.e. contain up to 30% concentration of the isotope plutonium-240. Weapon-grade plutonium should have no more than a few per cent of that isotope. The higher the concentration of Pu 240, the less predictable and weaker the explosion yield of the bomb. Weak in this context would mean weaker than most military nuclear weapons but large compared to most conventional charges.

Even if power reactors, optimally run, would produce plutonium unsuitable for bombs, it would be quite possible to run a reactor differently to get a "better" plutonium. In addition weapon-grade plutonium could be produced in research reactors and in special plutonium production reactors.

While plutonium is itself a nuclear fuel of great potential value all reactors are at present essentially fuelled with uranium, either natural or slightly enriched with the isotope uranium-235. This uranium is not usable for bomb-making – that would require almost pure Such weapon-grade uranium is now very scarcely available because it is used in a few research reactors only and because the facilities to produce it exist only in the nuclear weapon states. However, if uranium enrichment technology later becomes available to many nations a U 235 problem will be added to the Pu problem.

The terrorist case

For a terrorist or other sub-national group wanting their own atomic bomb, the most practical approach would be to steal bombs from a military depot. This would provide reliable bombs of high and predictable yields and avoid the cumbersome and difficult design and fabrication problems. If that is not possible the second best approach would be the seizure of weapon-grade uranium from a military stockpile, because uranium is much easier to handle than plutonium. If that also is impossible the third approach would be to steal weapon-grade plutonium from a military stockpile. As clandestine production of fissionable material in hidden facilities would be out of question for sub-national organizations, the last and least attractive possibility would be seizure of reactor-grade plutonium from civilian stocks. It is only that fourth possibility that is directly connected to the civilian nuclear power debate.

Should the terrorists choose the fourth possibility they will face the problems of designing and making the bombs themselves, which is not as easy as is usually claimed, particularly if the plutonium to be used is reactor-grade. It is true that most of the nuclear physics involved is available in the unclassified literature; but beside that there will always be a fair share of difficulties to overcome in the intricate and unromantic disciplines involved, i.e. electronics, chemistry, shaped charges, metallurgy etc. before the entire process would produce a nuclear bomb.

There are examples where students have designed an atomic bomb in the library of a university. But the designs we have seen have been very primitive and would probably not produce a bomb of nuclear size (or perhaps only a small one), should the student survive the manufacture! This is not a critical observation, however, because there is always the possibility that a group of qualified scientists or a professional bomb-maker who changed his loyalty will do that part of the job. Therefore, the solution to the plutonium problem must be physical protection of the fissionable material.

Fortunately, the prospects for solving this problem seem hopeful for two reasons. One is that it has been positively demonstrated for several decades that it is possible to protect effectively the huge arsenals of nuclear weapons and the military stocks of weapon-grade fissionable material. And there is no reason why the military protection procedures could not easily be applied also to civilian material. The second reason is that denying sub-nationals access to the bomb would be in the interest of all governments, without exception; accordingly, an international agreement on

minimum standards for protection procedures is now being prepared.

It is sometimes claimed that guarding the plutonium-stocks of the future would require such an effort that countries would have to turn themselves into police-states. This is clearly exaggerated. Protecting nuclear weapons has been successfully performed in several nuclear weapon states for a long time without turning them into police-states, at least for that reason.

International Proliferation

While the sub-national proliferation problem seems to be manageable and can probably be successfully solved, the prospects for denying access of nuclear weapons to national states seem to be less predictable. A general and widespread application of nuclear energy would furnish a number of countries with a good part of the necessary physical basis for bomb-making. The Non-Proliferation Treaty (NPT) was intended to take care of this problem before the nuclear industry had turned the many have-nots into potential haves. The treaty prescribes that haves shall not transfer any nuclear weapons to any recipient whatsoever and that have-nots shall continue as have-nots. The treaty prescribes further that the International Atomic Energy Agency (IAEA) shall verify that the peaceful nuclear industry is not used for bomb-making by have-not parties. This safeguard system is now in operation. But the treaty being essentially an expression of political intent has a number of weaknesses. Firstly, the subscription to it is far from universal. About 90 states are parties but a number of countries having a significant nuclear industry remain outside. Among these are haves like France, China and India and have-nots like Japan, Israel, South Africa, Brazil and Argentine, to mention a few.

Secondly, the safeguard system can only detect but not prevent the diversion of fissionable material to bombs. On the other hand the IAEA inspectors seem effective enough to be able to discover violations of the treaty at such an early stage that political counteractions can be properly organized, for instance by the UN Security Council. In addition, safeguards apply uniformly only in NPT-countries. They apply in part in a number of non-party states and not at all in some countries.

In addition, national states would of course have much better possibilities than sub-nationals, in both physical and economic terms, to carry through a nuclear weapon program. A state might for instance change the operation schedule of its nuclear power stations to produce a higher grade plutonium. And it might complement its nuclear fuel cycle to achieve more selfsufficiency in fissile material. But a state would on the other hand probably want their bombs for other purposes than would terrorists, and they would, therefore, need many more bombs and more predictable ones.

In coping with these problems, it is necessary to realize that the political will to stop proliferation is sometimes single-sided. Certainly most governments would agree that proliferation of atomic bombs among additional countries would be unfortunate. But when it comes to writing off their own nuclear option, a number of governments apparently hesitate.

Therefore, the problem should be approached in two ways. One is to convince states, which can make the bomb and want to make it, to change their minds by promoting the NPT and encouraging as many have-nots as possible to subscribe to it. The other is to organize joint policies influencing and restricting the nuclear industry in non-party, have-not countries.

The main responsibility for promoting the NPT would fall on the nuclear weapon powers. They alone can reduce the risk of nuclear aggression and they alone can remove certain discriminatory features of the NPT by agreeing among themselves on substantial measures of nuclear disarmament. Only such measures would in the long run convince the hesitating have-nots. A few agreements of this kind (SALT I) have been reached but most of them remain to be realized, and the rate of progress is not impressive. It is true that nine more have-nots, including several with a significant nuclear industry (Euratom) became parties to the NPT in connection with the recent Review Conference of the parties to the treaty. But one should have no illusion that universal pacification of the atom can be achieved soon by means of nuclear disarmament.

In addition to promoting the NPT there has always been an interest among states exporting fuel and equipment for nuclear power stations to see to it that their export does not support or become involved in any nuclear weapon program abroad. This aspect has been increasingly stressed after the Indian nuclear explosion last year. It is reflected in the NPT by a provision banning such export to non-parties unless the exported fuel or equipment is covered by IAEA safeguards. This provision in fact extends the application of safeguards substantially beyond the NPT-group of states.

Furthermore, leading export countries are now discussing joint export policies including a demand that IAEA safeguards shall apply not only on what is exported but on the entire nuclear industry as a condition for transfer of fuel, equipment and technological know-how. To be effective such policies must be uniformly subscribed to by the main exporting countries. Also recommended is the establishment of multinational nuclear fuel cycle centers, i.e. combining chemical reprocessing plants, fuel fabrication plants, waste management installations and long term spent fuel storage under multinational management minimizing the risk of both national and subnational diversion of plutonium.

Other measures have also been suggested such as: dispersed stockpiling of weapon-grade materials organized by the IAEA, in order to minimize the physical availability of such material in any single country; increased efforts to solve the remaining problems in recycling plutonium as reactor fuel, in order to encourage the consumption of existing plutonium as reactor fuel; international ownership, Euratom-style, of all fissionable material in all non-nuclear weapon states; and the general strengthening and improvement of the intensity of the IAEA safeguards system.

Concluding remarks

This analysis has so far avoided two drastic measures that could altogether solve the problem of civilian plutonium stockpiles. One is the cessation and banning of all nuclear power production in all countries, a measure that would finally and completely remove the whole problem of civilian stockpiles. The other is changing the role of the IAEA from international verification of NPT obligations to supranational management of all nuclear activities for peaceful purposes in all countries, a measure that would go very far in securing that atoms for peace would be atoms for peace for ever.

I do not intend to use this opportunity to plead for or against nuclear power in general. But it is necessary to state that neither of the two far reaching measures indicated above seems at present politically realistic on a global scale. No leader of any country has enough power to decide on measures like that. And even if such measures could be agreed upon, the huge military stocks of weapon-grade material would remain as would all the nuclear weapons. Therefore great efforts both to diminish the possibilities of diver-

sion of peaceful atoms to bombs, and to accomplish nuclear disarmament are our only realistic choice, because we will have to face the possibility that the nuclear power industry will continue to grow in several countries for several years to come and that the nuclear arms race will not stop by itself.

It will thus be necessary to reach agreement, within the next couple of years, among the sovereign states of the international society on a number of measures. A few that are presently under consideration shall be listed here:

- joint and uniform export policies requiring effective pacification of the recipient's nuclear industry as a condition for transfer of fuel, equipment and technological know-how;
- strengthening and improvement of the IAEA safeguards system;
- increased efforts to solve the remaining problems for recycling of plutonium;
- protecting stockpiles of plutonium and other special fissionable materials from seizure by terrorists or other sub-nationals;
- dispersed stockpiling of weapon-grade fissionable material organized by the IAEA;
- establishment of multinational nuclear fuel cycle centers and further measures to increase the international management of the nuclear power industry;
- a number of substantial nuclear disarmament measures.

It is certainly impossible to promise that such measures will be agreet to or that they will be fully effective if agreed. But as long as a nuclear power industry exists in a number of countries, such efforts would be necessary to make nuclear power more compatible with peace. The ultimate success could not be based on physical measures alone. There needs to be the combined political will of all countries to stop proliferation and to accomplish nuclear disarmament. In the long run this will be the essential factor.

Coming back to my initial question wether it will be possible to combine nuclear power with a peaceful world, the answer cannot be a clear yes. The terrorist problem could certainly be solved. But it is impossible to say that the proliferation problem would also be solved. It might or it might not, depending on the unpredictable political will of so many countries.

ETHICAL REFLECTIONS ON THE USE OF NUCLEAR ENERGY

ROGER L. SHINN

I. SKETCHES OF IMAGINARY FUTURES

Humanity is moving into a future so different from any familiar past, so loaded with portent and promise, so unpredictable that solid thinking about social and ethical decisions to be taken in that future is extremely difficult. For that reason an effort at loosening up imagination may be useful. Hence I shall sketch quickly four possible pictures of the world in the year 2100. Obviously all four cannot be true. I claim no truth for any one.

A. Technological Utopia

By the year 2100 the world has recovered from the near breakdown at the end of the 20th century. At that time the population of the globe had reached 6 billion, and about 10 million people starved in one year. Energy shortages disrupted the economies of several societies. There were sporadic revolutions in many parts of the world. Small countries and even terrorist gangs discovered that, even if they could not win a war, they could frighten the major powers into pay-offs.

In a sudden show of strength the U.S.A., the Soviet Union, and China collaborated to impose a world dictatorship. A combined military and scientific elite took over and imposed stern measures, which the world reluctantly accepted in order to avoid chaos.

Now, within slightly less than a century, the world population has been reduced to 5 billion people. Further reductions are planned, but it has been decided to move slowly because there is already a preponderance of older people. Governmental regulation of population is strict but fairly simple. The development of the 'ideal contraceptive' means that every youth is inoculated at puberty, and parenthood requires a specific decision and medical act.

The world is organized in regional economies. There is centralized planning, but regions are given some choices. For example, a region may choose to have low population with a high level of consumption or higher population with lower consumption. The inequalities of the past have been reduced but not ended.

There are no international armies, but a world police force and intelligence agency exercises strict surveillance. Activities destructive of the environment are prohibited. This means a close monitoring of inventions and industrial processes.

Historians now refer to everything prior to the 19th century as pre-history. The 19th and 20th centuries are called the time of primitive civilization, and they are divided into the coal age, the petroleum age, and the age of nuclear fission.

Since the second quarter of the 21st century oil reserves have remained "unused and unwanted in the ground as a consequence of a diminishing demand – arising from the abilities of man to harness and to use solar and fusion power and the preferences of consumers for these new forms of energy." (Peter R. Odell.) Large solar reflectors orbit the earth, remaining in fixed positions relative to the geography of the earth, and beam solar energy to receptors on the ground. Their use is precisely planned, not only to provide energy but to stave off the encroaching ice age detected by climatologists. Scientists are already worrying about what to do in a future era when the climate changes, and the earth overheats.

Historians recall the early part of the century with its exhaustion of some raw materials, particularly mercury, tin, lead, and zinc. But industry has compensated with new techniques of recycling and substitution. Scientists have invented "atom-transformers" – modern equivalents of the medieval "philosopher's stone", which they use not to turn base metals to gold but to turn the earth's crust into almost anything they want.

Work is done mostly by machines. For a time North American scientists advocated technologies that would enable 5% of the world's people to produce food enough for all. However, in order to avoid unemployment, the world government settled for an average of 20%. Industry is largely machine operated. For a time it seemed that there would be problems of too much leisure, but the world government met that by a moderate return from capital-intensive to labor-intensive production.

Public transportation is highly developed, but there are a considerable number of automobiles. The electric car never became popular, because of difficulties in developing compact and lightweight batteries. Cars are powered by hydrogen. Most people live in attractive environments and use sophisticated systems of communication, so there is less desire to travel than in past centuries. Homes are built according to styles originated long ago by Buckminster Fuller, and new building materials make housing plentiful for the reduced population of the world.

B. After the Nuclear Holocaust

Just how it started nobody knows. The evidence was destroyed in the war. The U.S.A. intelligence assumed that nuclear weapons landing on American cities originated in the Soviet Union, but that was only a guess. Rather than wait for more evidence, military authorities retaliated, and soon the world was involved.

Somehow due to a freak of atmospheric movements, most of Africa escaped the worst of the radioactive clouds that enveloped much of the world. America and Europe were desolate and remained so. Their cities are deserted. It is reported that a few people survived and still live there, but not much news reaches the rest of the world. China, it is said, is not so utterly destroyed as America and Europe, but it is in bad shape.

After the destruction Africa learned to live without any technological imports. The petroleum of Libya, Nigeria, and Angola was exhausted long ago. There are no airplanes, automobiles, or trucks. The great cities (Cairo, Nairobi, Dakar, Johannesburg) could not survive without petroleum, and they were evacuated long ago. Much of Africa learned without great trouble to adapt to rural tribal life.

The drought, which hastened the southward expansion of the Sahara desert, did great damage. Nobody knew whether it was due to natural causes or atmospheric changes brought about by the nuclear holocaust. For a time there was serious starvation, but Africa adjusted.

A few African historians of science are confident that they understand the technological skills of the late 20th century. They have annual meetings. They even talk about possibilities of inexhaustible supplies of energy through nuclear fission or fusion. But all their conversation is academic and theoretical. There is no adequate economic infra-structure to build the systems they talk about. Fires, for example, are mainly of wood. There is no steel industry.

Now and then somebody proposes the colonizing of Europe and North America. In these regions, there are said to be great deposits of coal and iron ores. It is conjectured that technologists could use raw materials from these under-developed countries as the basis for an industrial revolution. But it is rumoured that the radioactivity there is still too great for colonization.

The general assumption is that the future of humanity will be agrarian and that social units will be small and self-sufficient.

People occasionally speculate about the ruins of the abandoned African cities. There are legends and folk songs about the life that once prevailed in these cities, and a few traditional rituals are traced to their origins in urban life. Some people look on those cities with regret and envy. They appear to be a wonderful achievement, now denied to the present generation. Others look at them with revulsion. They represent a frantic way of life, combining privilege and oppression. It is rumoured that people in those cities scarcely knew their neighbours. Contemporary life looks better. Here people share their wealth and poverty. The arts belong to everyone. All join in common rituals and celebrations. Yet, say some, it would be pleasant if we could have just a little of the luxury that the bygone urban civilizations produced and used so badly.

C. The Nuclear Age

Looking backward, the choice now seems inevitable. Humanity, threatened with an energy shortage, had to choose the nuclear option. A few still disagree, saying that their ancestors should have opted for a simpler, less intricate technology and social order. But most people dismiss them as romantic neo-primitives.

Nuclear energy has been, in a way, a great success. But everybody also sees its problems.

Looking ahead, technological optimists and pessimists argue. The problems facing humanity are immense. But some say that we can expect continued research and new solutions. Others say that the "technological fix" has already shown its limitations and cannot assure rescue.

The world has become accustomed to a mix of productivity and austerity. Historians smile cynically when they report that people in the 20th century sometimes held up the U.S.A. and Western Europe as models for what they called the "developing countries". How, they wonder, could anybody, even in those intoxicated days, really have thought that India could ever have the number of cars per capita of the U.S.A.? Or how did aeronautical enthusiasts ever assume that half the human race would use air transportation?

Energy now comes primarily from "nuclear parks". The world has 3,000 of these. The average one includes eight fast breeder reactors, producing 40 million kilowatts of electricity. To achieve this, humanity started in the late 20th century to build four new reactors per week. Now it is continuing that pace of expansion, but it is also building two more per day to replace worn out ones.

A large part of the world's economic activity is used to prepare and transport the nuclear materials, to dispose of the wastes, and to seal off the worn out reactors. Fifteen million kilograms of plutonium-239 are processed and transported each year. (Mesarovic and Pestel)

A worldwide surveillance system operates to prevent accidents, sabotage, and robbery. The system was accepted reluctantly, but after a few accidents and acts of terrorism the world decided it was necessary. There is constant monitoring of the nuclear parks, the waste disposal system, and the materials in transit. The guards are themselves monitored in a complicated system.

A central world authority enforces safety standards and supervises disposal of wastes. The salt mines of the U.S.A., the U.S.S.R., and China are valuable for waste disposal. Initially these countries refused to accept wastes from outside their borders, but eventually they agreed under pressure to take exported wastes.

There is an increasing feeling that the system may be getting unmanageable. Some see the answer in a successful fusion reactor. Every decade of the past century has heard promises that it will soon succeed, but its technology has proved elusive.

D. The Planned Society

In the peaceable world of 2100 historians are still trying to understand how humanity made the transition from the insecurities of 1980. Some emphasize the counterculture within the industrialized societies of those days: the movement of people satiated with competitive industrialism to the point where they fled the cities and took up subsistence homesteading, either in family units or communes. Others point to the example of China, which established a self-sufficient economy by deliberately exalting human labour over advanced machine-labour and by requiring all citizens to spend some time in common labour. Still others accent the contribution of the Club of Home, an organization of technological and intellectual elites, which adopted the slogan, "Earth is our home," and predicted disaster unless humanity adopted life styles less destructive. A different group of historians say that humankind, haunted by fear of war and economic failure, was ready for any social system that promised security. Finally, there are those who say that a movement of prophetic mysticism, arising simultaneously in scattered parts of the world, let to the Refrev – that combination of reformation and revolution that modified human values and aspirations on such an amazing scale at the turn of the century.

Somehow the human race did what everybody had said would be impossible. It engaged in a large scale effort at social planning. There were, to be sure, disgruntled resisters. But a majority of humanity got caught up in the movement and persuaded or pressured the rest into going along.

What was most amazing was the combination of groups not used to working together – mystics and technologists, capitalists and socialists, to some extent even rich and poor. Some were lured by the vision of a new style of life, others moved by the threatened disaster accompanying old styles. The slowest to change were the political and economic leaders of the wealthy societies, who did not want to give up what they had. But they finally had little choice when a series of international cartels, formed on the pattern of OPEC (a 20th century Organization of Petroleum Exporting Countries) withheld exports, and when several threats from nuclear-armed terrorists in starving societies scared them out of their wits.

When E.P. Schumacher won the Nobel prize in economics, the fraternity of economists first gasped, then took a look at his work. Five years later a poll showed that 77% of professional economists took him seriously. Schumacher made peace with the

Club of Home which he had been criticizing caustically. The United Nations sponsored an international conference that charted a new pathway for the world.

The globe was organized into a large number of economic units, relatively self-sufficient. International trade was drastically reduced, partly because it was becoming intolerably expensive in the face of petroleum shortages and price rises.

Use of nuclear energy was phased out, by international agreement, by the year 1995. All nations contributed through the UN to a research fund for development of alternative forms of energy, especially solar. Meanwhile there was a concerted effort to reduce energy consumption. Price mechanisms were already having that effect; a combination of rationing with tax policies tending to equalize wealth moved the process along. Travel and transportation – both international and domestic – have been greatly reduced by the year 2100. People cannot afford to travel much, and cities are designed to bring together opportunities for employment, living, and recreation. Sophisticated communication systems compensate in part for personal travel. Research funds go into public transportation systems. Private ownership of automobiles is forbidden, but people may rent cars (powered by methanol, made from sewage wastes) for special occasions.

There is some grumbling about a culture that constantly emphasizes economy, moderation in consumption, and the laborious recycling of resources. Some people say that creative enterprise is stifled, but others point to the resources that go into technological research, for example, in organic farming, in energy production, home designing, and utilization of substitutes for scarce resources.

Two years ago television networks in Europe and the U.S.A. began showing ancient films of the 1970's. Public authorities moved to suppress the films, saying that they were a pornographic titillation of illicit desires. There was widespread protest in the name of freedom of speech. Suddenly public authorities changed their policy. Instead of forbidding the films, they bought them and ran them repeatedly on the air. Their explanation was that the films, showing the intense frustrations in affluent societies, especially when alternated with films of wars in those days, were a sound education for people who compared the miserable past with the better present.

II. ETHICAL AND SOCIAL ISSUES

This exercise in imagination has its foolish aspects. Anybody looking at it ten years from now will ask why I picked these four sketches and omitted others. No doubt some are asking that now.

The point is to emphasize that social and ethical issues are concrete and historical. They depend in part on an empirical base. Before making a social and ethical judgment, I must ask: What are the real possibilities? What are the probable outcomes of different choices? What risks are involved?

But social and ethical judgments do not derive solely from "objective" data. They depend partly on visions, purposes, commitments. What is a good society? What is it to be human? Since to be human is to be a dreamer, what dreams are worthy to inspire our energies? Alvin Weinberg shows how scientific judgments keep edging into the trans-scientific. Wolf Häfele describes the situation of hypotheticality. Note that the realms of the trans-scientific and of hypotheticality themselves include two kinds of components. The one is a shortage of tested information that requires a venture into the unknown. The other is a conflict of visions as to what is good.

I shall here raise some issues and ask some questions. Some of my questions can, at least in principle, be answered by empirical data. Or perhaps I shall be told that the data are not available. I am accustomed to that situation. If I have my teeth X-rayed, I am balancing the benefits of the X-rays against the harm that they may do to my body. I do not know precisely the risk but I accept the best technical judgments I can get. If new evidence becomes available tomorrow, I may change my practices.

Other questions probably cannot be met by empirical data. After all the available evidence is in and after new evidence becomes available, I must still ask what I prefer for myself and my heirs. What kind of society will win my loyalty? For what goals will I make commitments, accept risks, and enter into sacrifices?

In this context of double uncertainty – factual and valuational – I shall examine a few issues.

A. Attitudes on the Relation of Humanity and Natury

The species called humankind is obviously part of nature, of an ecosystem. Yet humanity has qualities not shared by the rest of nature – ability to envision futures, make choices, bend environment to human purposes. Many attitudes are possible about the efforts of humans to take charge of nature. I mention two, chosen for the sake of contrast.

Hermann J. Müller, the famous geneticist, wrote in 1966:

> *Of course, we – that is humanity – will take our biological evolution into our hands, and try to steer its direction, provided that we, humanity, survive our present crises.*
>
> *Have we not eventually utilized, for better or worse, all materials, processes, and powers that we could gain some mastery over?*

Barry Commoner, on the other hand, coined the aphorism, "Nature knows best". Since that is obviously figurative speech, he explained his meaning (1971) that "any major man made change in a natural system is likely to be detrimental to that system."

Perhaps neither Muller nor Commoner is literally accurate. But they express two moods, two spirits, two wills towards human control over nature. Their statements are related to classical debates about humanity and nature: to the Chinese controversies between Taoists and Confucians, the Hellenic discussions of nature and custom, the Renaissance comparisons of nature and art. Is the highest human destiny to fit into a natural system, loving and enjoying it? Or is it the human privilege to replace nature with artifices? Or is the best plan to accept nature, cherish it, and yet transform it? There are analogies here to the classical theological discussions of the relation between nature and grace.

B. Risk

There is no life without risk. In biblical theology risk is inherent in the human situation, and security is an idol. There is nobility in some risks. Is it not better to take risks, even to sacrifice one's self for an ideal, than to cling to static security?

But some risks are rash and irresponsible. There is a special ethical problem in imposing risks upon others for the sake of ourselves. Perhaps there is a peculiar issue in imposing risks upon the unborn who are powerless to defend themselves. Informed consent has become an important ethical principle in medical exper-

imentation. But future generations cannot possibly give informed consent to our acts that destroy possibilities for them.

Yet we know that we are beneficiaries of past risks. There was the risk of the first biological species that left the ocean and ventured to live on land. There were the risks of prophets who defied powerful authorities in obedience to a divine call. There were the risks of the heroes of liberty.

Likewise, we are victims of people who have taken risks for inadequate ideals, imposed their wills as conquerors on subject peoples, and shed blood to spread their creed and notion of good.

What are we to say of the ethics of the risks involved in nuclear energy? For an estimate of some of these risks most of us must simply look to scientists. They know more than the rest of us about the risks of radioactivity or of the malfunctions of systems.

When scientists differ, the rest of us must be perplexed. There is little truly "objective" data that we can comprehend. At this point I have an inclination to trust the disinterested scientists rather than those who have a stake in the success of their own ventures, simply because I trust myself most when I am disinterested. By disinterested I do not mean uncommitted.

When scientists move their evaluation of risks into the social and historical area, as indeed they should, more of us can get in on the discussion. We can learn something about what it means to build plants that must be kept safe, both when in use and when worn out. We can barely understand the meaning of nuclear wastes with a half-life of 24,000 years and a dangerous radioactivity for 200,000 years. We can begin to imagine the problems of guarding and protecting large quantities of dangerous materials under transportation across continents.

I am grateful for Alvin Weinberg, who in his advocacy of fission reactors, says: "But the price that we demand of society for this magical energy source is both a vigilance and a longevity of our social institutions that we are quite unaccustomed to." I appreciate his pointing out the importance of "surveillance in perpetuity". *(Anticipation,* No. 20, p. 13.)

My mind boggles when I try to multiply present risks by thousands, as I must do to grasp the problem, then to project it over the next century. If then somebody talks about thousands of years, I hardly know how to respond. My own country is now preparing to celebrate its bicentennial. I must ask, where has a stable society persisted for a thousand years? How often are natural systems stable for 10,000 years? In the face of such questions I find persuasive the warnings of Alvin Weinberg and Hannes Alfvén, different though their conclusions be. Without knowing for certain the answer, I must ask myself what present need justifies imposing a burden upon future generations for centuries to come?

C. Present and Future Values

Presumably the life of someone a few generations hence is as valuable as mine. But I am likely to favour mine, simply because it is mine. I am likely to favour my children's welfare over the welfare of my great grandchildren, because I know and love my children but have not seen my great grandchildren.

Furthermore, the future is unknown. In balancing present realities against future possibilities, I accent the present. The American baseball manager, Leo Durocher, always used his best available pitcher, saying, "Tomorrow it might rain." We know too little about the future to take it into account as forcefully as we do the present.

But at what point does unconcern for the future become morally irresponsible?

Most of us would take actions to prevent starvation now, even at considerable risk to future generations, who may learn how to handle the risks that we impose on them. But how much risk have we a right to impose on future generations for the sake, not of saving lives but of providing jobs for the unemployed – especially when unemployment is a function of an economic system that could be changed by other methods than stimulating production? How much risk have we a right to impose on the future for the sake of simple convenience and luxury now?

William Pollard pointed out that natural supplies of copper, tin, zinc, uranium, and even iron, which took "a billion or more years" in their formation, will be largely consumed in this century. He continued: "Men will look back on the 20th century as the age in which their spaceship was wrecklessly raped and her precious stores, accumulated over billions of years, were wastefully and thoughtlessly squandered." He added that fossil fuels, produced over a hundred million years, will be largely consumed in one century. He came to the conclusion that, if this human course should continue, "it can only prove to have been a cosmic blunder to have ever allowed man to evolve on this earth". (*This Little Planet,* pp. 60, 61, 64.)

Pollard requires me to ask whether the exorbitant demands for energy, required by our social systems, are part of a suicidal life style. To moderate that life style would be exceedingly difficult and, given present institutions, would inflict suffering on many defenseless people. Yet might it not be more ethically responsible to take the painful step now than to defer it until a time when catastrophe will be greater?

Of course, there is much about the future that neither I nor anybody else knows. It is silly to be overly confident of our projections, either of technological triumphs or of doom. But it is both silly and immoral to court disaster recklessly.

Herbert Butterfield, the distinguished historian and theologian, wrote:

> *The hardest strokes of heaven fall in history upon those who imagine that they can control things in a sovereign manner, as though they were kings of the earth, playing Providence not only for themselves but for the far future – reaching out into the future with the wrong kind of farsightedness, and gambling on a lot of risky calculations in which there must never be a single mistake. (*Christianity and History, *p. 104.)*

To agree with Butterfield is not to decide precisely what risks are admirable, what are irresponsible, and what are uncertain. It is to raise a question that most societies have not considered in any depth.

D. Economic Justice

Any form of power can be used for justice or for injustice. That is perhaps a cliché. Yet it requires constant re-examination. Was it C.S. Lewis who said that the supposed power of man over nature is in fact the power of some men, by managing nature, to control other men?

If we are here thinking about a general characteristic of human societies, it may have no special relevance to nuclear energy. But we should at least point out that the production of nuclear energy, by its very nature, requires a considerable concentration of wealth and power, possible only to a government or a major corporation. That is not in itself a reason to challenge nuclear energy, but it is a reason to watch closely its uses.

For example, we need to ask whether nuclear energy will be one of the many forces in modern society to increase the gap between rich and poor nations and between rich and poor in the same society.

We must also ask of nuclear energy, as of many other social phenomena, whether the costs are accurately assigned to those who get the benefits. Modern industry has often operated with deceptive accounting systems. It frequently turns a handsome profit by imposing hidden costs on innocent bystanders. For example, the costs of industrial pollution are paid, not primarily by the owners of industry or the consumers of its products, but by people who happen to live downwind or downstream from factories. The costs of the automobile are born partly by producers and consumers, but to a considerable extent by people whose neighbourhoods are torn apart by highways, even though these people cannot themselves afford to buy cars.

Any proper cost accounting for nuclear energy must reckon in not only the direct cost of production, but also the cost of experimentation, often born by government and not charged to the enterprise, and of surveillance now and for generations to come.

To raise this issue does not presuppose an answer that is negative towards nuclear energy. If it seems to do so, it is because that kind of question is so often neglected, either by technologists who plan operations or by industrialists who profit from them. Governments are theoretically in a good position to raise the question, but in practice they raise the questions that economically and politically powerful people want to raise.

E. Political Power

Inevitably we must ask about the role of corporations and of government in the production of nuclear energy. We can assume that in some societies corporations will do their best to persuade governments to pay a major share of the bills while the corporations reap the profits. So government participation, either in the actual production of energy or in the supervision of it, if government gives a voice to the people, may be a real advantage.

The cause for concern is the heightened power that may accrue to government in an age when people seem to find it increasingly difficult to make government responsible to their needs. Surveillance of nuclear operations is needed to protect people against accidental or malicious damage. To whom shall we entrust the surveillance? To a Richard Nixon and his White House gang, to a Vorster, to the military clique that rules Chile? The prospects are foreboding, even if we do not mention the generation of political leaders that perpetrated World War II. What happens to personal freedom in an age when technological operations are so intricate that concentrated authority must impose controls?

I hope I am not communicating the notion that I see a special demonry in nuclear power production or in technology in general. I think those who idolize or demonize technology are equally erroneous. I do say that those technological achievements that concentrate great power, when incorporated into social systems that are already inadequate, require us to ask social and ethical questions. Ideally, the intricacy and scale of nuclear fission might contribute to a heightened sense of the interdependence of humanity thereby raising human ethical sensibility. But it might equally well contribute to a heightened authoritarianism that bears down unduly on the weak.

The international political implications are equally important. If nuclear production of energy becomes commonplace, no nation can be indifferent to the safety standards of other nations, whether this concerns the hazards of production, of waste disposal, or of possible theft and destructive use.

The awareness of the international meanings of energy production might conceivably be an advantage in an age that has to learn how to outgrow certain kinds of nationalism. But the international corporations have shown us that internationalism does not necessarily bring power closer to the people. If a politically powerful nation and its weak neighbour each have a stake in the safety standards within the other country, one might hope for some kind of equality of provisions for inspection. But one might more probably expect an increased domination of the powerful over the weak.

Such political issues arise whenever a sophisticated technology enters into immature political systems, which seem to be the only systems we know.

F. Relation to Military Technology

Large scale production of energy by nuclear fission, I have already observed, means the multiplication of materials that can be used destructively by governments or by terrorists. In that way it obviously heightens the risk connected with widespread dispersion of exceedingly potent weapons. (See Frank Barnaby, *The Nuclear Age.)*

In another sense the relation of nuclear fission to military technology is important. The first major ventures in nuclear fission were part of a wartime effort to make weapons of unprecedented power. It is, of course, good that many of the people involved began immediately to look for peaceful uses of this scientific-technological achievement. It would be naive to reject a humanly helpful technology because it originated in a military effort. Humanity needs all the help it can get, and it had better not turn down any.

The question that must be asked is whether the relation of nuclear fission to weapons has vastly skewed governmental expenditures for research. The question almost answers itself. The immense research costs of developing nuclear fission would not have been authorized apart from military purposes. We must then ask what might have happened if the same money and intensity of effort had gone to devising other forms of energy or other social structures that might make life enjoyable without so much expenditure of energy. When we are told that technologies for using solar energy are not nearly as effective as nuclear technologies, is the reason inherent in the scientific nature of the case? Or does it result from the priorities that societies, for military reasons, have assigned to one kind of research?

There may be a curious circular argument at work here. That is, we may be choosing one form of energy production because the technology for it is more promising than for others; and it may be that the technology is more promising simply because we have chosen to emphasize that option.

G. The Meaning of Human Existence

On many social and ethical issues, I have said, my judgments will be influenced by the data that scientists produce. But finally we come to some judgments on which the poets and prophets, and indeed our own intuitions, have as much bearing as do scientific data.

Biblical faith testifies that humans do not live by bread alone. Yet the sacramental acts of Judaism and Christianity, the celebration of the Passover and the Lord's Supper, are acts of eating. This faith is neither materialism nor spiritual escapism.

Analogously we can say that humans do not live by physical energy alone, yet do live by the expenditure of energy. An energy policy, explicit or implicit, is part of every human life and society. The question is what human life style best expresses the profoundest meanings of life. Do the modern industrial economies, which some societies have achieved and to which many others aspire, best express the meaning of human life? Do they enslave or liberate the human spirit?

Curiously, Western civilization still lives to a significant degree from spiritual reservoirs of two ancient societies: the Hellenic and the Hebraic. Both ante-dated modern technology. Both were, by modern standards, societies of low consumption. They were certainly not ideal societies. They were always fighting their neighbours, and they were filled with political and economic injustices. Yet they showed some human possibilities that still illumine history.

If asked whether I want to return to their technology, I must say that I clearly do not. I am a person of my time and my culture. My world is a world of transoceanic air travel, central heating, telephone, television, hospitals, free institutionalized public education, availability of books. Such a world has formed me, and I would be uncomfortable in any other.

But whether this world can be sustained, I do not know. And how much of it is important to the pilgrimage of humanity, I do not know either. What am I, what is my culture, capable of giving up? What would we be better without? I don't know that.

What I think I know is that we had better entertain questions that we have never dared to face in this generation. To raise the questions, as I have done here, may seem to make me negative toward nuclear energy. That is partly because it is the business of ethics to raise questions that are often conveniently neglected, and the raising of questions may seem to be obstructionist, even if it is not.

But my aim is still to ask questions, to seek answers, and to be open to persuasion. So I would formulate my final question or pair of questions thus: Will nuclear energy offer the possibilities of a better human existence, bringing opportunities to many that have been available only to a few? Or would human societies be better with a simplified life style, involving reduced consumption of industrial products and bringing people closer to each other and to nature?

Our answer will in part be forced upon us as, for example, a reduced consumption of petroleum has lately been forced on many people. But our answer will be partly our choice. Our choices will be made in that bewildermen characteristic of humankind, where people choose with little knowledge of consequences and where events often seem to generate a momentum that governs choice. Certainly our choices cannot be infallible.

Yet it is important that we choose. To do less is to renounce our human gifts and potentialities.

REMARKS ON THE ETHICAL IMPLICATIONS OF NUCLEAR ENERGY

GÉRARD SIEGWALT

It is reported that at the end of the First World War the German Emperor Wilhelm II said: "Das hab' ich nicht gewollt" (I didn't want that). I think it is important for us to remember this affirmation when we consider what I would call the apocalyptic horizon facing us. We spoke during this Ecumenical Hearing of the risks, the dangers that surround us; the dangers from nuclear energy as it is becoming available to humanity which may not be sufficiently prepared for assuming responsibility for this new technology. In view of this horizon where catastrophes are impending dialogue is for us of greatest importance.

Since last year we have at Strasbourg University an interuniversitary seminar with representatives of the different disciplines which are concerned about the ecological problem. What has impressed us most in this seminar was the recognition of the fact that the different disciplines have each their own language so that the university resembles very much a tower of Babel. There are so many languages that there is great difficulty in finding a common language. It is the significance of a Hearing like this that we feel that we are more and more condemned to dialogue and pushed to find again a common language between the different disciplines. In this context I want to put forward the following four considerations:

The **first** consideration is an ecological one. Ecology has taught us that everything is related to everything, that there is an interrelationship between humanity, nature and matter. This means that a sectarian approach to reality – a unilateral approach to reality – will have effects on the other parts of reality that have been forgotten, and these effects may be very great. Ecology teaches us that there is also a limit to the earth, to the resources of the earth, to the possibilities of the earth and its inhabitants. We experience in a new way the finitude of man and earth. It has been urged that the regulative function of ecology be recognized by the different disciplines, so that the separate approaches to different aspects of reality be all referred to the one earth and to the one humanity on this earth. I think this ecological consideration has to be kept in mind when we approach the energy problem.

My **second** consideration is an epistemological one. Epistemology is the science of knowledge – to say it in a simple way: epistemology deals with the lenses through which we look at reality. If these lenses, these eyes through which we perceive reality are different, the reality as we see it will also be different. What is the epistemological assumption of the Western world? I have to be very brief: The Western world has followed the French philosopher Descartes who distinguished between the subjective reality of man, the *res cogitans,* the *ego cogito,* and on the other side, the objective nature which is object to human analysis and transformation. This is the Carthesian dualism which leads to what Marcuse calls in a special sense (but it is also true in a broader sense) the one-dimensionalism by which either the one side, the objective nature, or the other side, the subjective attitude of man, is absolutized. We live today in such a civilization where there is a gap, a split within and between human beings, a split between humanity and nature. The efficiency of this concept is very clear, we see it – it is our industrial and technological civilization, but we have also to see the weak basis on which this civilization is founded In his book, *Die Einheit der Natur,* Carl-Friedrich von Weizsäcker distinguishes between two illusionary systems *(Wahnsystem).* He describes one of the illusionary systems as being entirely illusionary, thus completely inefficient, and of little danger. But there is also another *Wahnsystem,* that is more dangerous because it is partially right. Weizsäcker asks whether our Western civilization is not such a *Wahnsystem,* that is dangerous because of its partial truth, and consequently its partial error. From this perspective, the nuclear problem we are dealing with is not only a technical one. There is also a philosophical and epistemological problem involved: What has already happened? What assumptions are made when we think in a merely scientific, objective way? I think this is the deeper issue we are confronted with: we should know that we are working on assumptions that may be questioned. This is not only a theoretical or even rhetorical deliberation. History, even recent history, teaches us that issues which are raised in a one-sided way provoke resistance from those aspects of reality that have been neglected or not sufficiently taken into account. But, though having been forgotten at one point, they will come back into the centre of man's memory at another moment in history.

The **third** consideration is an economic one. The concern for a sufficient energy supply which will satisfy humanity's energy needs is, in its place, a justified and good concern. The achievement of this goal involves planning. But there are two questions: (a) What are the motivations of economics? Are they also one-dimensional? Are they purely functional? Are they only related to economic man as a producer and consumer? Or is economics part of an integrated view of man and the whole world in which the economic concern is open to other concerns? (b) What are true and what are false economic needs? The distinction between real and wrong needs becomes necessary in a civilization where we have gadgets. Often we are overwhelmed by the delusions of basically superfluous needs. Hence the question: Is the assumption that electric energy will be doubled in ten years taken for granted? In the light of our quest for an examination of true and false needs, this assumption has to be challenged. The criterion for answering this question is the criterion of legitimacy. What is legitimate according to the view of humanity and according to the reality of earth?

My impression is that nuclear research is not condemned by these questions but that it should perhaps be used in a functional way, not so much as a producer of energy on a wide scale but for specific interventions where these are necessary. I refer to a parallel example: Using merely chemical fertilizers leads to a disequilibrium of the natural equilibrium. Chemical fertilizers may however be a complementary addition to organic fertilizers. As such they may be good, but used alone, they create a problem.

My **last** consideration is a theological one. I think that when

we try to see together the different aspects we are faced with and to resist thinking in a sectarian, a unilateral one-sided way, then we are approaching in a new way the question of God. We are confronted with totality which transcends, which is greater than we are, but which we see appear. Thinking which is open for all the aspects that may be grasped by us, is necessary if we want to be in harmony with the whole of reality. Here we see a need for a theology of nature or of creation which enables us to relate every single aspect to the totality. When we try to do this – for it can only be an attempt – we may in a new way understand what the Bible calls the fear of God. In view of the totality of things we may understand the saying: The fear of God is the beginning of wisdom. This affirmation is directly in line with what I call the apocalyptic horizon in which we are placed. We seem to be experiencing anew today what the Greek called *moira* (fate). We realize that elements of reality which we have brought forward may follow their separate line, in their own way become autonomous, and finally demonic for humanity, leading to the disintegration of man and reality. There is then the invitation to what the Bible calls *metanoia,* the new thinking, and that means a thinking which is considering totality. Therefore the attempt to integrate thinking and dialogue as we try to have it here belongs to the worship of God as much as prayer does. Dialogue, integrative thinking, prayer, all are ways in which the fear of God is lived today, in which it can become real for us today. Through integrative thinking, dialogue and prayer, the *ecclesia,* the Church, is gathering, is occuring. A new community is being created and such a reality of *ecclesia* as we are experiencing it here is a hope for humanity and for the future.